Journal

of

THE ROYAL AERONAUTICAL SOCIETY

JUNE 1959

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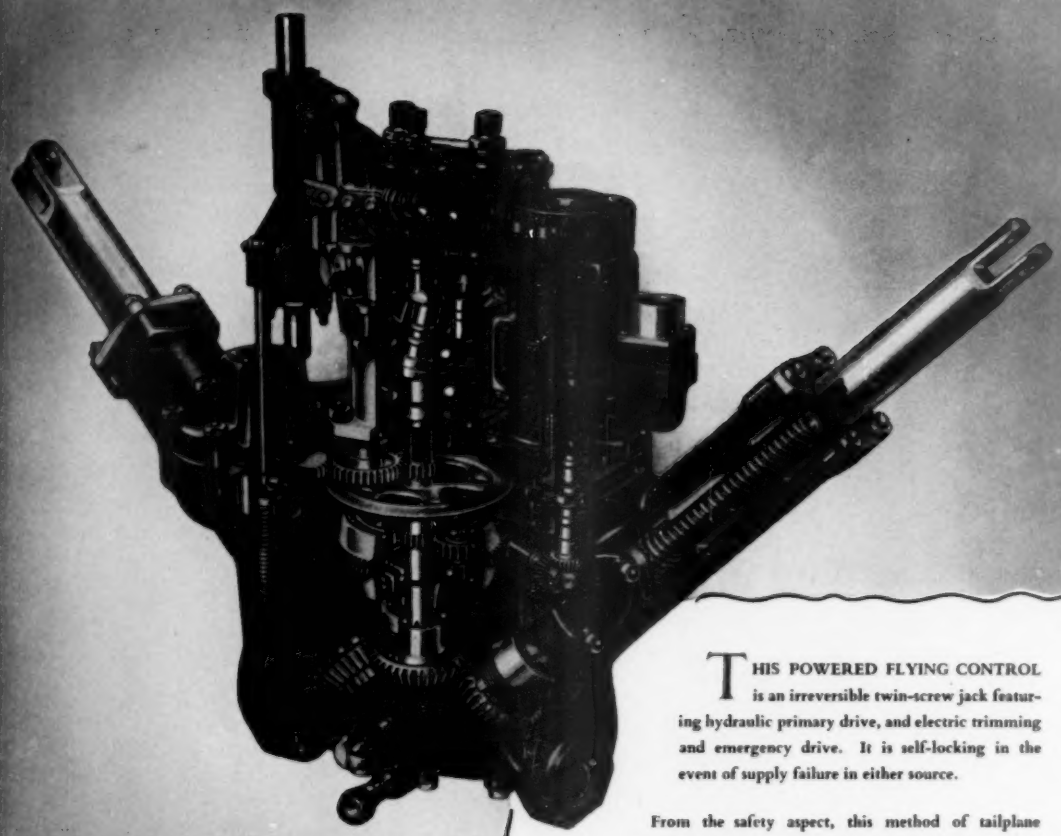

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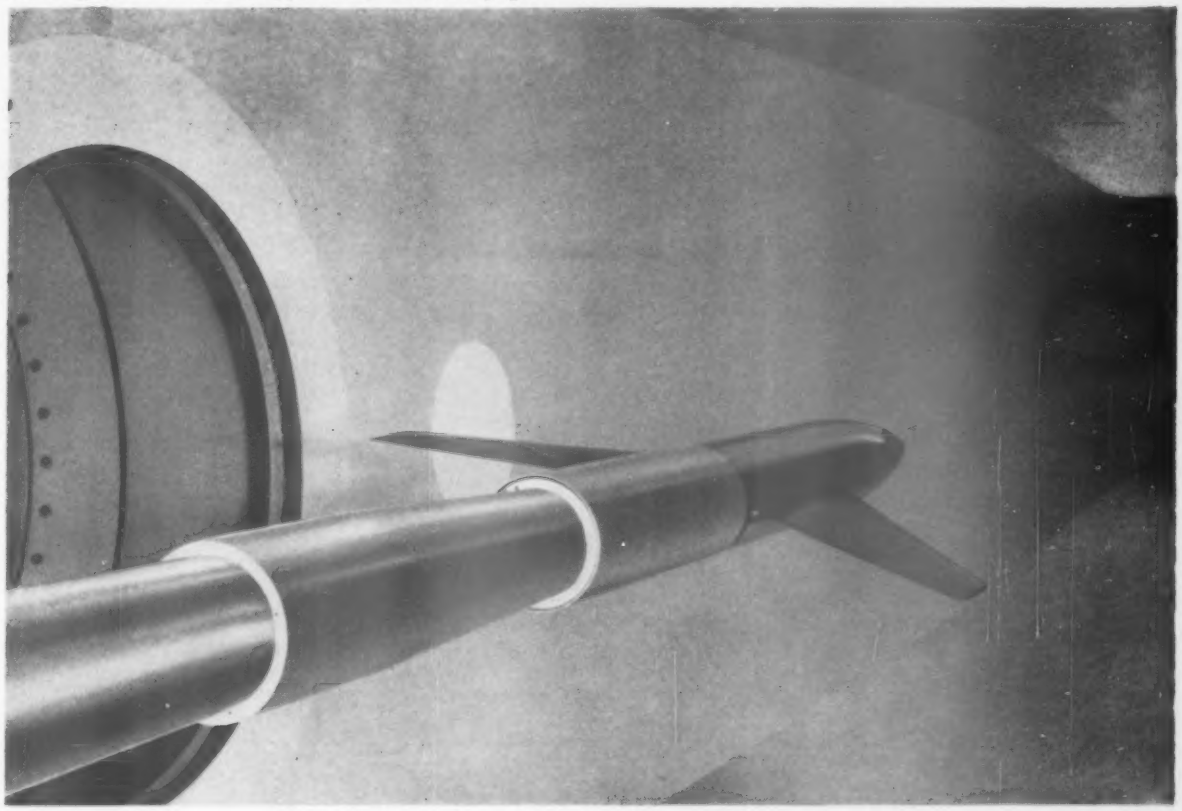

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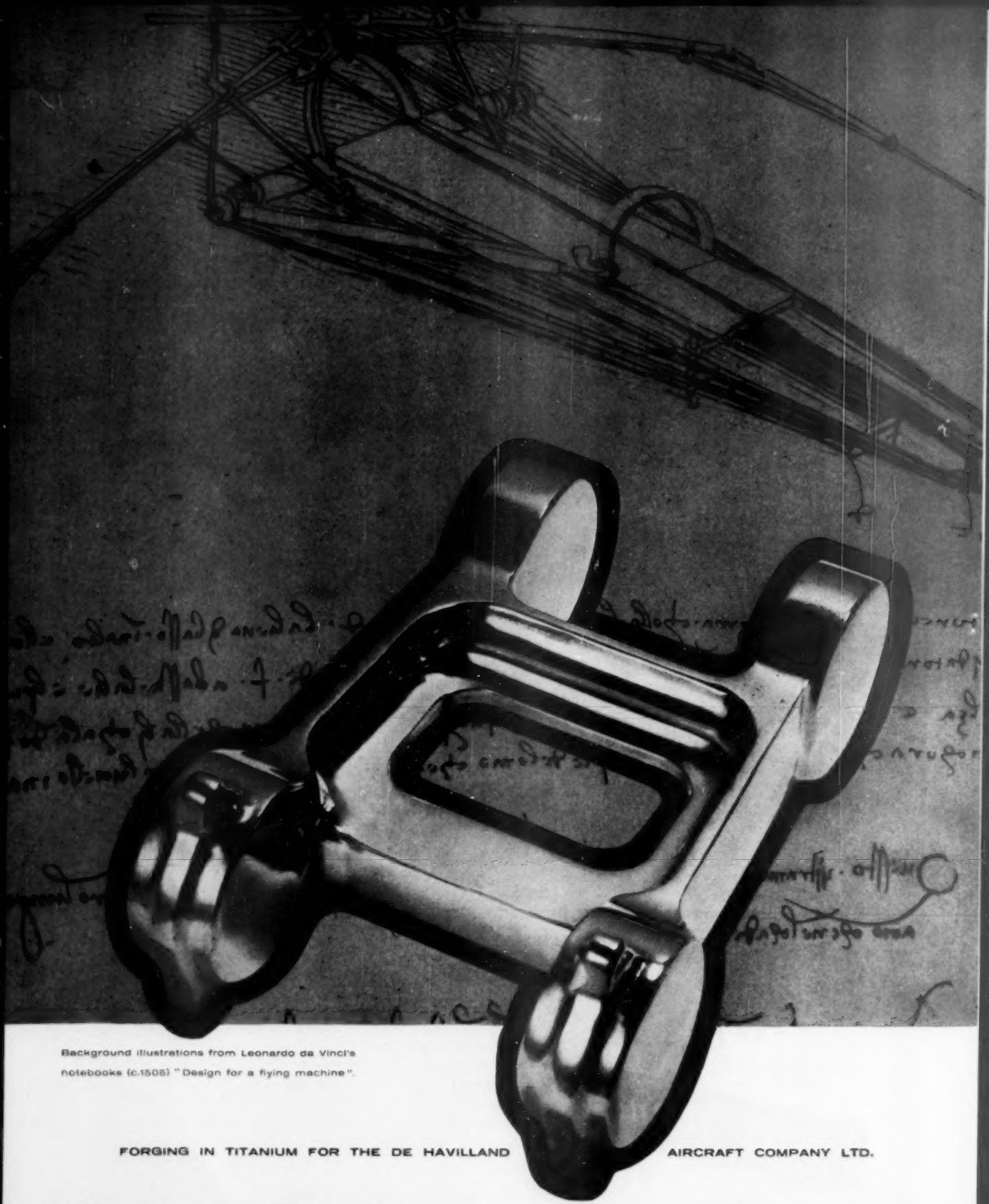

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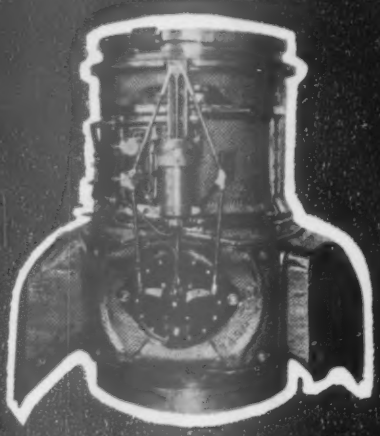

1

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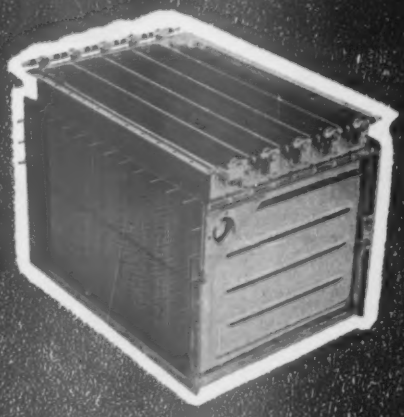

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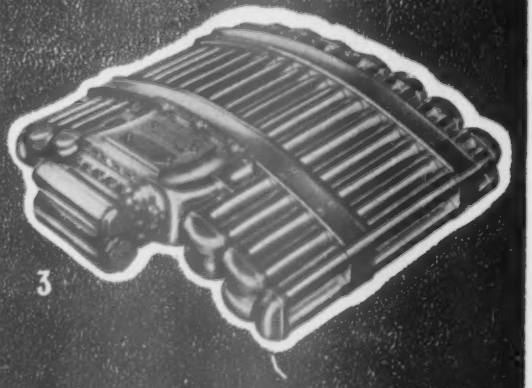

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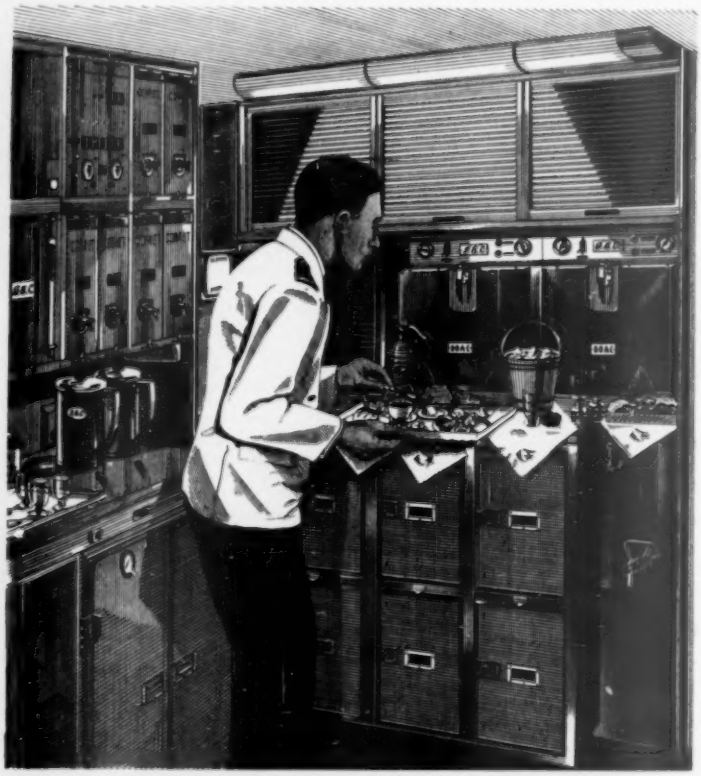

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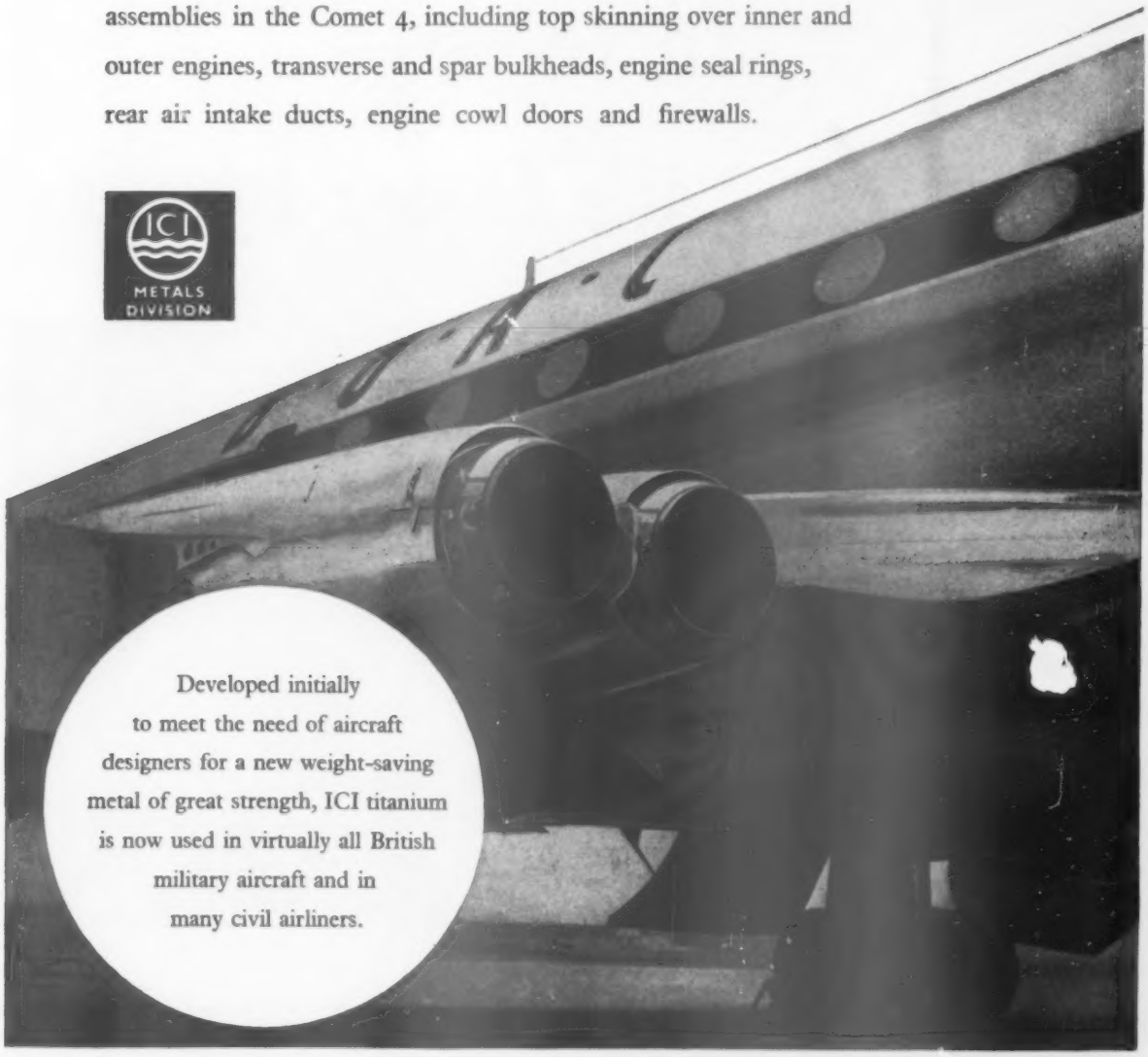

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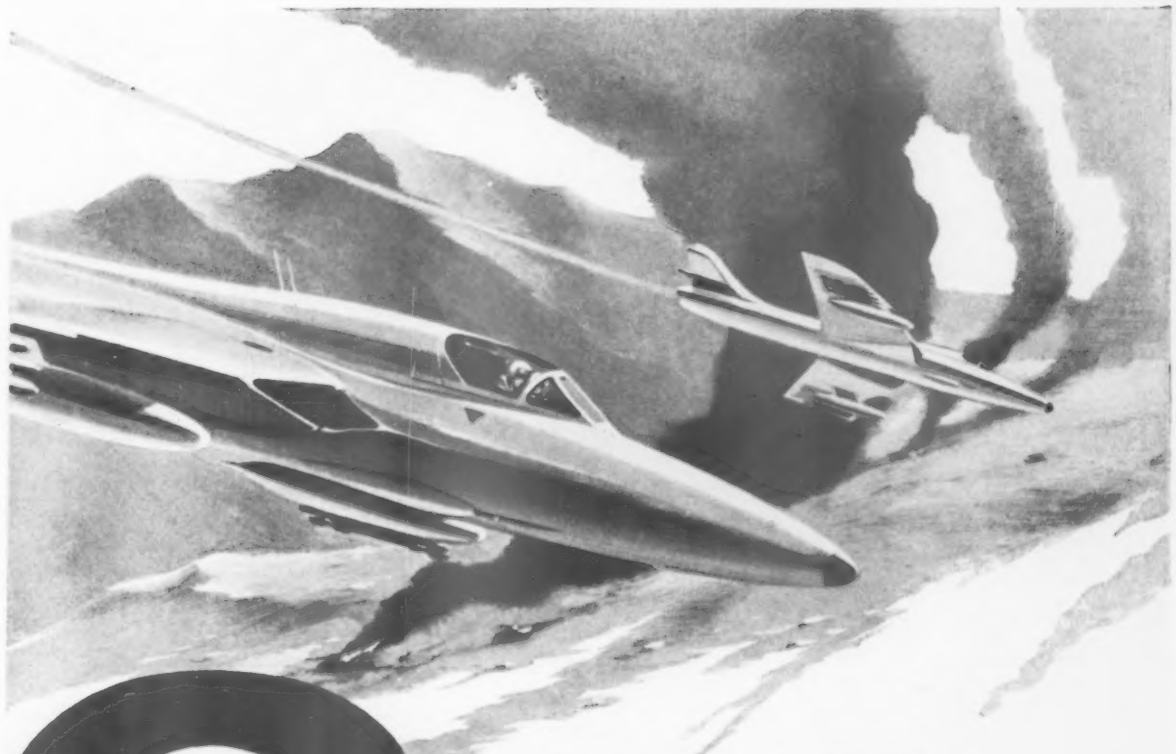

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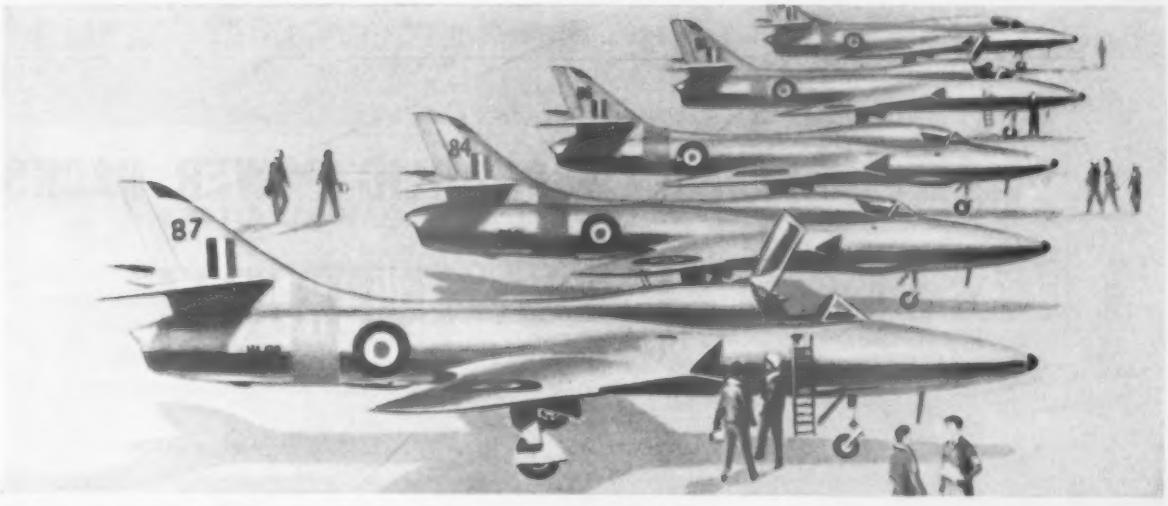

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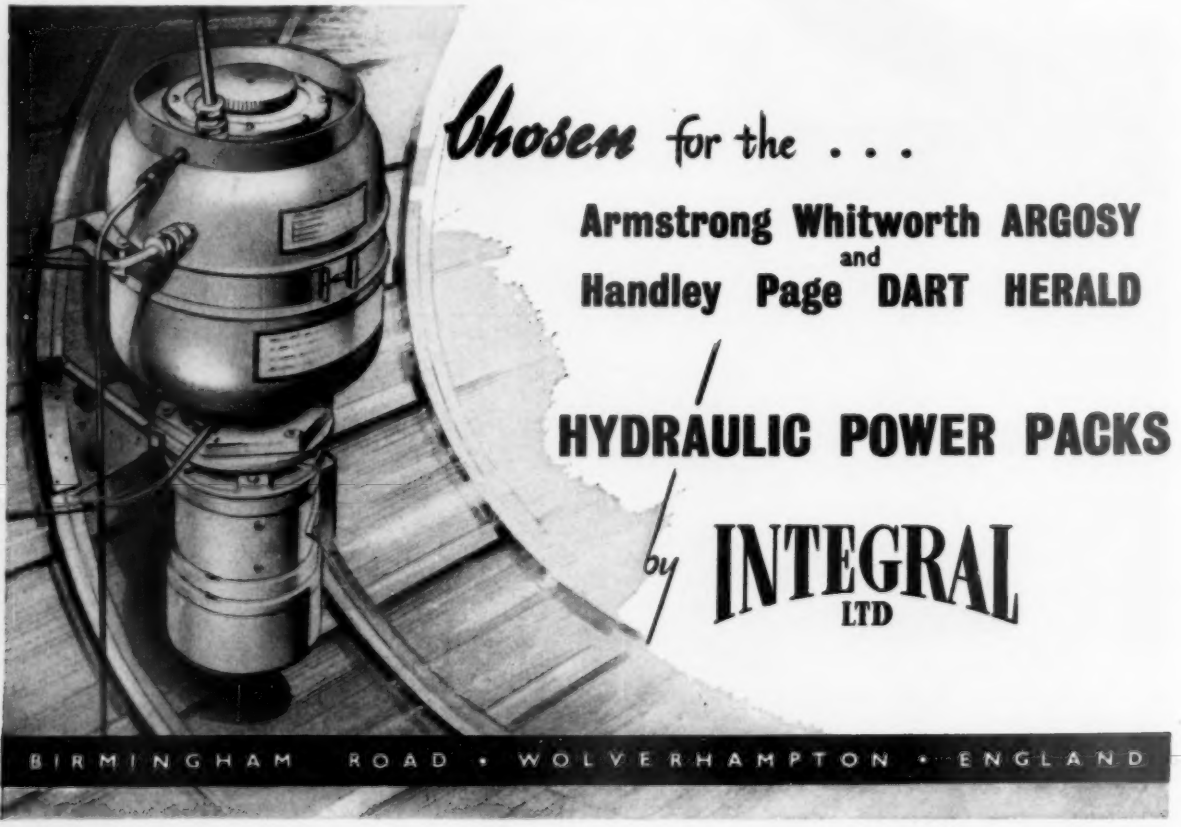

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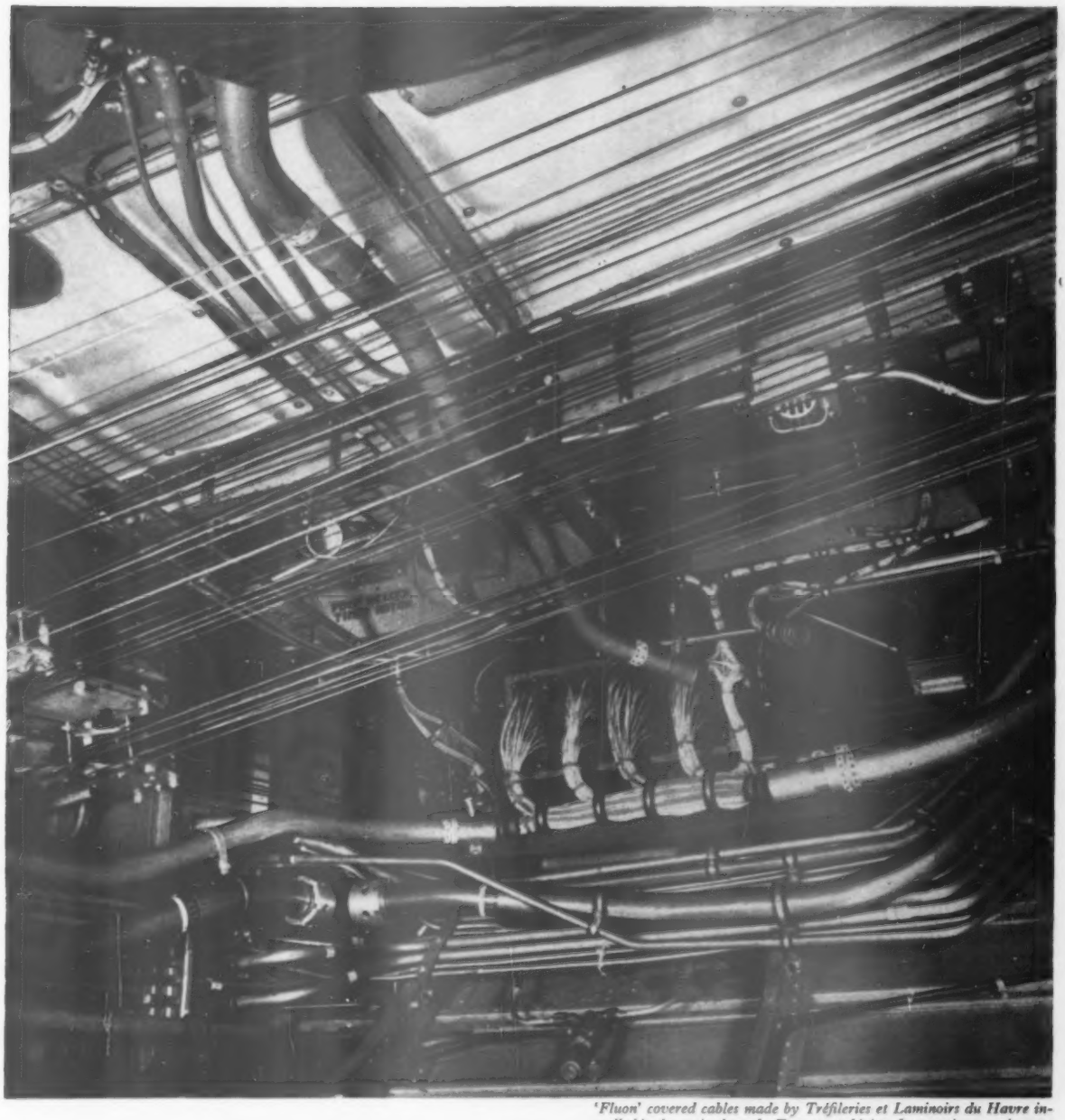

'Fluon' covered cables made by Tréfileries et Laminoirs du Havre installed in the engine bay of a Transport Aériens Internationaux aircraft.

'Fluon' covered cables in French aircraft

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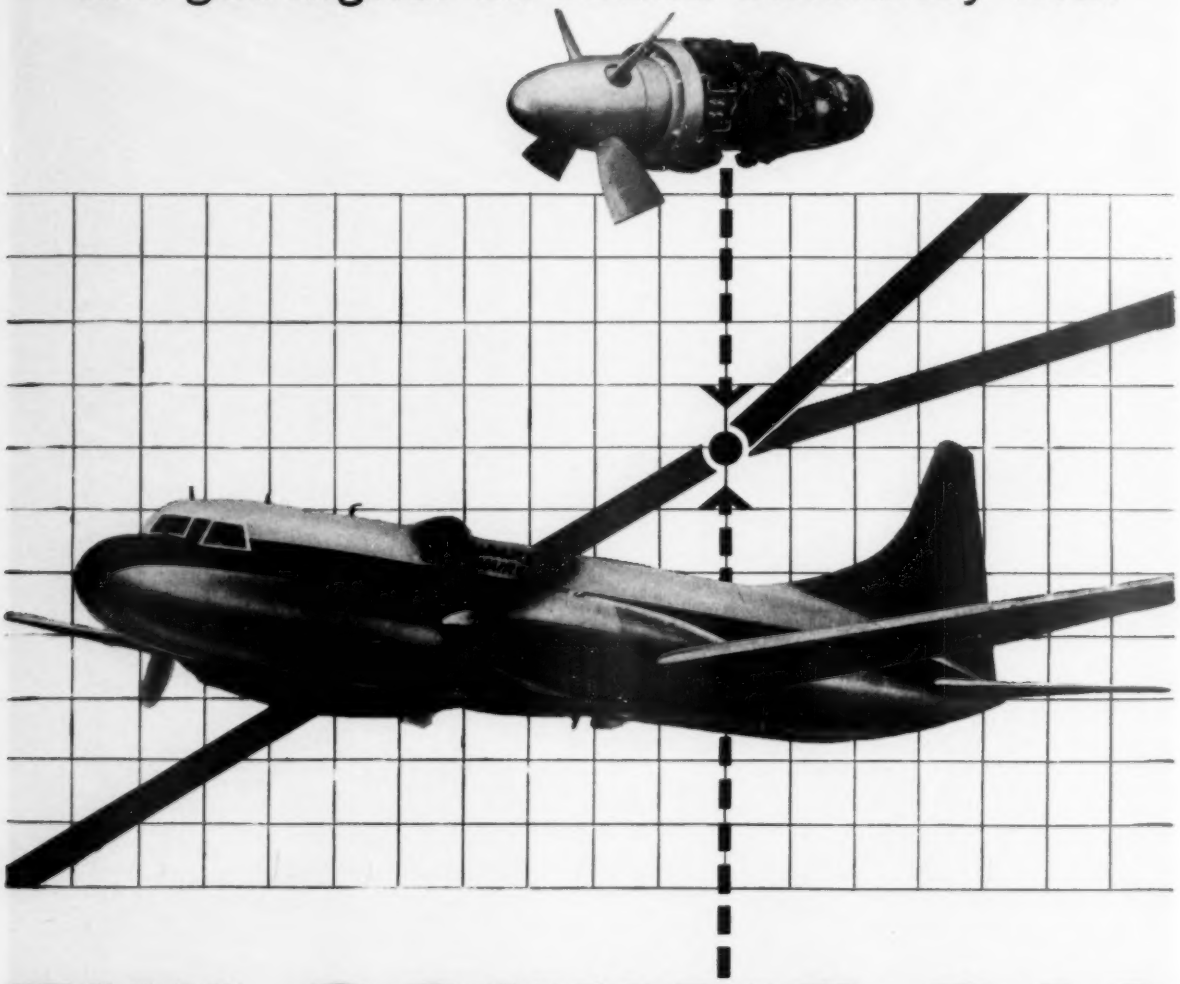

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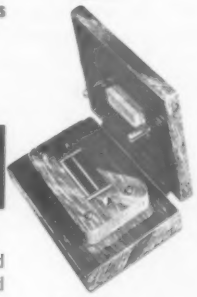

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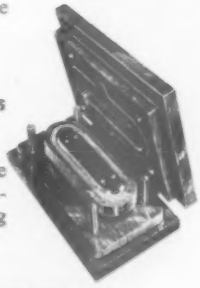

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AP27

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WALLACE D. HAYES, *Princeton University and Space Technology Laboratories, and*
RONALD F. PROBSTEIN, *Brown University and AVCO Research Laboratory*

June 1959, 465 pp., illus., 82s.

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The treatment covers, from a hydrodynamic point of view, the basic theory of the characteristically hypersonic features arising in flow fields about bodies at flight speeds far greater than the speed of sound.

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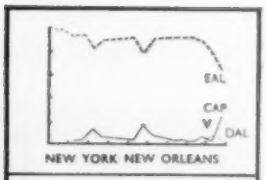
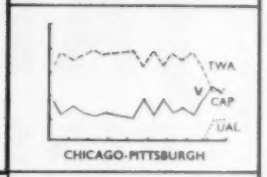
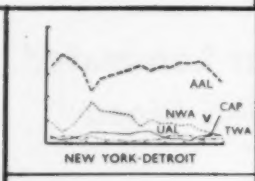


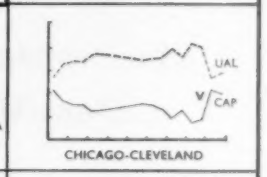


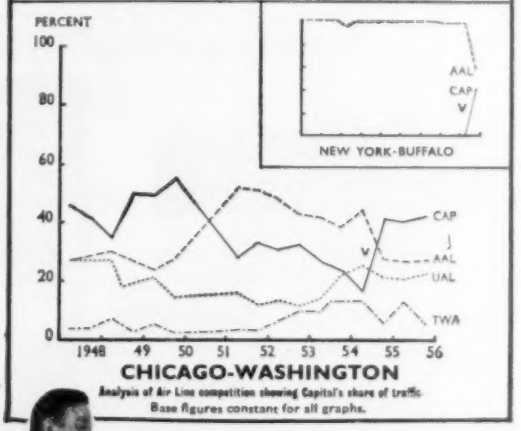
Competitive impact of Viscount 700 a vital factor in Capital's resurgence V=Viscount Upsurge

A recent article in the American "Journal of Air Law and Commerce" (from which the adjoining graphs are reproduced), draws attention to the upsurge of Capital Airline's share of traffic following their introduction of Viscount services. The article continues, "The increase in Capital's share . . . is by no means a simple result of CAB policy. A closer look at Capital's traffic indicates that the competitive impact of the Vickers Viscount was also a vital factor. The remarkable upsurge of Capital in the 1956 section of each of these graphs follows the initiation of Viscount service. The Chicago-Washington route effectively exemplifies Capital's revival in 1955 with the initiation of Viscount services. By March, 1957, this dominance had increased from 42 to 55 per cent, while American's share dropped to 17 per cent". (V indicates period of time the Viscount was first introduced.)

Now, the Viscount 810/40 offers operators even more profitable operation than earlier Viscounts. Payload, speed and range have all been substantially increased, without raising air mile costs, giving considerably greater earning power.







More impressive facts about the VISCOUNT 810

- **Take-off weight now 72,500 lb. (up 3,500 lb.).**
- **Landing weight, zero fuel weight and payload all increased by 2,000 lb.**
- **Maximum-payload range increased from 800 to over 1,200 miles.**
- 365 m.p.h. When re-engined with more powerful Darts, 400 m.p.h.
- Backed by Vickers/Rolls-Royce turbo-prop experience of over 300 Viscounts in service with 40 airlines.
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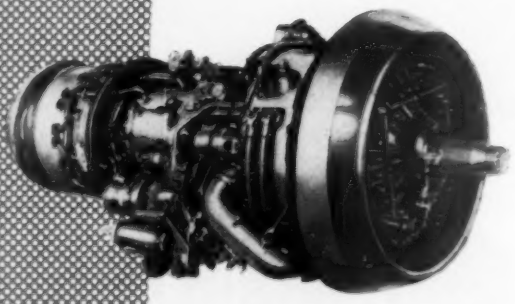

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ADDITIONS TO THE LIBRARY. REPORTS.

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June 1959

NOTICES

Garden Party 1959

In view of the many extra commitments being undertaken this year, regretfully the Council have decided not to hold a Garden Party. It is hoped that this will prove only a temporary absence from the Society's activities.

President of the Society 1959-1960

Mr. P. G. Masefield, M.A., M.Inst.T., Hon.F.I.A.S., F.R.Ae.S., President of the Society for the year 1959/60, took Office at the Annual General Meeting held on Thursday 7th May 1959.

President-Elect

Dr. E. S. Moult, B.Sc.(Eng.), M.I.Mech.E., F.R.Ae.S., Vice-President of the Society and Technical Director, de Havilland Engine Company Ltd., has been elected President-Elect of the Society for 1960-61.

Vice-Presidents

The following have been elected Vice-Presidents of the Society for 1959-60:—

Air Marshal Sir Owen Jones, K.B.E., C.B., A.F.C., B.A., D.I.C., M.I.Mech.E., F.R.Ae.S.
Air Commodore F. R. Banks, C.B., O.B.E., M.I.Mech.E., Hon.F.I.A.S., F.R.Ae.S.
Professor A. R. Collar, M.A., D.Sc., F.I.A.S., F.R.Ae.S.

Council for 1959-1960

The following are the newly elected Members of Council as a result of the Ballot declared at the Annual General Meeting:—

*A. D. Baxter (*Fellow*)
Dr. W. Cawood (*Fellow*)
*Professor A. R. Collar (*Fellow*)
*Sir Harry M. Garner (*Fellow*)
D. Keith-Lucas (*Fellow*)
A. A. Rubbra (*Fellow*)
B. S. Shenstone (*Fellow*)

*Re-elected.

Annual General Meeting

The Annual General Meeting of the Society was held at 4 Hamilton Place, London W.1, on Thursday 7th May 1959, at which the Annual Report and Balance Sheets of the Royal Aeronautical Society and Aeronautical Trusts Limited for 1958 were approved. The Report and Balance Sheets were published in the April 1959 Journal.

The retiring President, Sir Arnold Hall, presented certain of the Society's Prizes and Awards to the recipients.

New Fellows 1959

The following elections to Fellowship were announced at the Annual General Meeting on 7th May 1959:—

Charles Bayly
Leslie H. Bedford
Raymond L. Bisplinghoff
Edward G. Broadbent
Edmond A. S. Brun
Tadeusz L. Ciastula
Edward C. Cornford
Noël Daum
Sir Vincent Z. de Ferranti
William D. Disbrey
Robert R. Duddy
Wladyslaw Fiszdon
Oliver L. L. Fitzwilliams
Robert H. Francis
Richard W. G. Gandy
Ferdinand B. Greatrex
Lionel Haworth
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Richard J. Ifield
Francis E. Jones
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Peter Lloyd
Sir Arthur W. B. McDonald
Arnold W. Morley
Wilfred N. Neat
Griffith G. Roberts
Henry Roberts
Norman C. S. Rutter
Edward R. Sharp
Albert G. Smith
Alec J. Tyndale-Biscoe
Jacques Valensi
Cedric O. Vernon
Eric J. Warlow-Davies
Henry R. Watson

Library

The Library will be closed on 16th, 17th, 18th June, and on the morning of 19th June.

Honorary Fellows

Honorary Fellowship, the highest honour the Society can confer, has been awarded to the following:—

Professor J. Ackeret (Professor of Aerodynamics at the Eidgenossischen Technischen Hochschule)
Sir William S. Farren, C.B., M.B.E., M.A., D.Sc., F.R.S., M.I.Mech.E., Hon.F.I.A.S., F.R.Ae.S. (Technical Director, A. V. Roe and Co. Ltd.).
S. B. Gates, O.B.E., M.A., F.R.S., F.R.Ae.S. (Chief Scientific Officer and Consultant to the Director of the Royal Aircraft Establishment).

Honorary Companions

The following have been made Honorary Companions of the Society:—

E. C. Bowyer, C.B.E. (Director and Chief Executive of the Society of British Aircraft Constructors).
Sir William Hildred, C.B., O.B.E., M.A. (Director-General of the International Air Transport Association (I.A.T.A.)).

International Agricultural Aviation Conference

Members are reminded that offers of short papers or progress reports are invited for this residential Conference, which is to be held at Cranfield from 14th-19th September 1959. Synopses must be received by the organising secretary at the Ministry of Agriculture **by 27th June** and **complete papers by 25th July.** Information for intending contributors may be obtained from: The Secretary, International Agricultural Aviation Conference, Room 218, Great Westminster House, Horseferry Road, London S.W.1.

Medals and Prizes of the Society

The following Medals of the Society awarded by the Council were presented by Mr. P. G. Masefield, President 1959-60, at the Wilbur Wright Memorial Lecture on 14th May 1959. The Scrolls of Honorary Fellowship and Honorary Companionship were also presented on this occasion:—

The Society's Silver Medal—awarded for work of an outstanding nature in Aeronautics—to:

Dr. E. A. Watson, O.B.E., D.Sc., Hon.M.I.Mech.E., Director, Joseph Lucas (Gas Turbine Equipment) Ltd.

"for his achievements in the development of turbine engine combustion and fuel systems."

The Society's Bronze Medal—awarded for work leading to an advance in Aeronautics—to:

D. G. King-Hele, B.A.
Royal Aircraft Establishment, Farnborough

"for his contributions to earth satellite orbital theory."

The British Gold Medal for Aeronautics—awarded for outstanding practical achievement leading to advancement in Aeronautics—to:

R. S. Stafford, C.B.E., *Fellow*
Technical Director, Handley Page Ltd.

"for his outstanding practical contributions to aircraft design."

The British Silver Medal for Aeronautics—awarded for practical achievement leading to advancement in Aeronautics—to:

D. J. Farrar, M.A., *Fellow*
Chief Designer, Guided Weapons, Bristol Aircraft Ltd.
and
N. H. Searby, Ph.D., M.I.E.E.
Manager, Guided Weapon Research and Development, Ferranti Ltd.

"for their practical contributions to the development of guided weapons."

The Wakefield Gold Medal—awarded for contributions towards safety in Aviation—to:

K. A. Wood

Superintendent in Charge at the Atomic Weapons Research Establishment, Orfordness,

"for his practical achievement in the development and application of electronic aids to all-weather approach and landing."

The R. P. Alston Medal—awarded for practical achievement associated with the Flight Testing of Aircraft—to:

A. W. Bedford, A.F.C., *Associate*

Chief Test Pilot, Hawker Aircraft Ltd.

"for his contributions to the technique of flight testing high-speed aircraft."

The N. E. Rowe Medal—awarded for the best lecture given before any Branch of the Society by a junior member of a Branch—in the age group 21 to 26 years—to:

J. Dunham, M.A., G.I.Mech.E., *Graduate*

Rolls-Royce Ltd.

"for his paper 'Damage to Axial Compressors' given before the Derby Branch of the Society."

No award was made this year for the under 21 age group.

NOTE—The Society's Gold Medal was awarded to Monsieur Marcel Dassault and presented at the Louis Blériot Lecture on 12th March, 1959.

The following Medals and Prizes of the Society, awarded by the Council, were presented by the retiring President, Sir Arnold Hall, at the Annual General Meeting on 7th May 1959:—

The Simms Gold Medal, for the most valuable contribution read before, or received by, the Society on any subject allied to Aeronautics— to:

Mr. R. P. Probert, *Associate Fellow*

Deputy Director, Engine Test Facilities, National Gas Turbine Establishment,

"for his paper 'Ram-Jets'." (March 1958 JOURNAL.)

The George Taylor (of Australia) Gold Medal, for the most valuable contribution read before, or received by, the Society on Aircraft Design, Manufacture or Operation —to:

Mr. H. L. Cox, *Fellow*

National Physical Laboratory,

"for his paper 'The Application of the Theory of Stability in Structural Design'." (July 1958 JOURNAL.)

The Edward Busk Memorial Prize, for the most valuable contribution published in one of the Society's publications on Applied Aerodynamics—to:

Mr. T. R. F. Nonweiler, *Associate Fellow*

Department of Aeronautical Engineering, Queen's University, Belfast,

"for his paper 'The Man-Powered Aircraft—A Design Study'." (October 1958 JOURNAL.)

The Orville Wright Prize, for the most valuable contribution to "The Aeronautical Quarterly" of the Society on some subject of a technical nature in connection with Aeronautics—to:

Dr. D. A. Spence, *Associate Fellow*

Royal Aircraft Establishment, Farnborough,

"for his papers 'The Lift on a Thin Aerofoil with a Jet-Augmented Flap' and 'Some Simple Results for Two-Dimensional Jet-Flap Aerofoils'." (August and November 1958 QUARTERLY.)

The Herbert Ackroyd Stuart Memorial Prize, for the most valuable contribution to the Society's publications on Aircraft Propulsion—to:

Mr. A. A. Lombard, *Fellow*

Director of Engineering, Aero-Engine Division, Rolls-Royce Ltd.,

"for his paper 'Thinking About Aircraft Engines'." (May 1958 JOURNAL.)

The J. E. Hodgson Prize, for the best paper of a general nature, with emphasis on historical work published by the Society—to:

Mr. J. E. Allen, *Associate Fellow*

Head of Aerodynamics, Project and Assessment Department, Weapons Research Division, A. V. Roe and Co. Ltd.,

"for his paper 'From Aviation to Astronautics'." (September 1958 JOURNAL).

The Branch Prize, for the best paper on an aeronautical subject read before the Branches of the Society and published in the Society's publications—to:

Mr. B. D. Blackwell, *Associate Fellow*

Engineering Manager, Bristol Aero-Engines Ltd.,

"for his paper 'Some Investigations in the Field of Blade Engineering'." (September 1958 JOURNAL)

The Navigation Prize, for the best paper on navigation, including meteorological instruments and test equipment, published by the Society—to:

Mr. C. M. Cade

Research Department of Kelvin and Hughes Ltd.

"for his paper 'Radio-Astronomy and Navigation'." (November 1958 JOURNAL.)

The Usborne Memorial Prize, for the best contribution to the Society's publications written by a Graduate or Student on some subject of a technical nature in connection with aeronautics—to:

Dr. J. S. Przemieniecki, *Associate Fellow*

Bristol Aircraft Ltd.,

"for his paper 'Matrix Analysis of Shell Structures With Flexible Frames'." (November 1958 QUARTERLY.)

The Pilcher Memorial Prize, for the most valuable paper read by a Graduate or Student during the previous year at any meeting of the Society or Branches—to:

Mr. A. W. Kitchenside, now *Associate Fellow*

Aircraft Project Office of Vickers-Armstrongs (Aircraft) Ltd.,

"for his paper 'The Effects of Kinetic Heating on Aircraft Structures'." (February 1958 JOURNAL.)

SUPPLEMENT TO OXFORD ENGLISH DICTIONARY

A Supplement is being prepared to the *Oxford English Dictionary*, the Editor of which is asking for the assistance of members in tracing early references to aeronautical terms.

From time to time, a list will be published in the JOURNAL wherein the earliest known use of a word will be given. Should any reader be aware of an earlier use, he is asked to write to the Editor, Oxford English Dictionary Supplement, 40 Walton Crescent, Oxford, giving the reference(s), date, author, title, chapter and page. The first such list is given below.

absolute ceiling	1931	*Handbook of Aeronautics*
actuator	1920	L. Bairstow, *Applied Aerodynamics*
aerial mine	1915	F. A. Talbot, *Aëroplanes and Dirigibles of War*
aerial torpedo	1910	*The Times* (also noted *aerial torpedo-boat* 1908, H. G. Wells, *War in the Air*)
aerial warfare	1908	H. G. Wells, *War in the Air*
air arm	1917	*Flying*
air corridor	1948	*Daily Mail* (also noted *aerial corridor* 1933)
air cover	1942	*Picture History of the War*
aircraft carrier	1919	*The Times*
aircrew	1939	*Aeronautics*
air ferry	1932	*Flight*
air flow	1915	*Aeronautics*

LECTURE THEATRE APPEAL

The appeal brochure has been distributed widely, to all members, to the Aircraft Industry, and to others likely to be willing to give their support.

The President and Council wish to thank all those who have shown by their ready response their approval and satisfaction with the scheme. A full list of the subscribers, up to the time of going to press, is set out below.

The model of the Lecture Theatre made by Sir W. G. Armstrong Whitworth (Aircraft) Ltd., has been much admired, and to them are due the thanks of all members of the Society for this generous assistance in providing such a useful adjunct to the plans.

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H. A. Wise, Esq.	1 1 0	
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		*364 18 6

**With Income Tax at the present standard rate of 7/9 in the £, this figure should produce £4200 (approx.) over the 7-year period.*

Bankers Orders for an Unspecified Number of Payments	£ s. d.	£ s. d.
M. M. Golovine, Esq.	1 1 0	
Dr. D. Küchemann	5 0 0	
Capt. J. L. Pritchard	10 0 0	
Flg. Off. H. W. Rabbitts	2 0 0	
		18 1 0
		£1296 9 10

In addition, donations in kind have been promised by the following firms:—

CIBA (A.R.L.) Ltd.
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Stop Press—*Since this list was compiled a deed of Covenant has been received from Bristol Aircraft Ltd., which will produce £5,000 over a period of seven years.*

Elections

The following is a list of elections and transfers of membership of the Society:—

Associate Fellows

Shaikh Tabarak Ali (*from Graduate*)
James Joseph Ansell (*from Graduate*)
David George Baker (*from Graduate*)
Donald James Bradford (*from Graduate*)
Samuel Lewis Bugg
Edmund Rashleigh Chaytor
James Guy Coop (*from Graduate*)
John Holt Eaton-Shore (*from Associate*)
Derek Eaves (*from Student*)
William Ponter Escreet (*from Companion*)
Trevor Gerald Evans (*from Graduate*)
Cyril Robert Fletcher (*from Graduate*)
Anthony Peter Hedley Bruce Fowle
Bertram Charles Gray
Ivor James Gregory
Philip Frederick Grieve
Eldred James Hallas (*from Associate*)
Charles Jeffrey Hayward
Paul Henry Leyton
Hugh Metcalfe
Alfred Hubert Frederick Murphy
Richard George Proudlove (*from Student*)
Peter Frederick Reed
Alan George Robertson (*from Graduate*)
Edwin Ivan Rusted
Joseph Sacharin (*from Companion*)
Mohamed Saeed (*from Graduate*)
Lewis Carter Sergeant
Gerald Frederick Short (*from Graduate*)
Austin Geoffrey Smith
Peter Duncan Stewart (*from Graduate*)
Ronald Townsend
Dennis John Tyler (*ex Graduate*)
John Henry Whiting (*from Associate*)

Associates

George Edward Boutall
Harry Grant Boyne (*from Student*)
Ian Frederick Burns
Louis Dawson
William Edward Drew
Sidney Hardaker
Derrick Ralph Marshall
Eric Norman Maynerd
Malcolm Hammond Niblett (*from Student*)
Paul Savoulides
John James William Spereall
John Richard Harding Stafford

Graduates

Anthony Andrews (*from Student*)
Leslie John Stanley Bradbury (*from Student*)
Gerald Augustine Cotterell (*from Student*)
Anthony Cockshut Cowin
Laurence Charles Ward Dixon
Sydney Lawrence Dixon
Leslie Eames (*from Student*)
Matthew Richard Gordon-Clark
Neil McKeand
Gordon James Thomas

Students

John James Louis Brennan
Leslie William Diment
Thoralf Fossheim
Alan Grimes
John Malcolm Harrison
Nicolas David Caldicott Ingram
David Blair James
John Michael McNeil
Frederick Charles Macey
Ronald Anthony Miller
Lim Thean Tet
Roger Geoffrey Trout
Sukhdeo Kumar Verma

Companions

John Reginald Brown
Norman James Allen Deaton

News of Members

L. R. E. Appleton (*Fellow*), formerly Chief Engineer, Weapon Division, Fairey Aviation Co. Ltd., is now a Director of Fairey Aviation Ltd., General Manager of the Heston Division, and a Director of Fairey Engineering Ltd., Stockport.

H. S. Bluston (*Student*) has left Canadair Ltd., and is now a Senior Aerodynamics Engineer with Republic Aviation Corp., Long Island, New York.

J. R. Bradford (*Associate*), formerly Sales Manager, Engine Division, Bristol Aeroplane Co., is now Sales Manager, British Oxygen Aro Equipment Ltd., Harlow.

Sqdn. Ldr. A. W. Culmer, R.A.F. (*Associate Fellow*), formerly with R.A.F. Upwood, is now Officer Commanding Engineering Squadron, Aden.

R. R. Duddy (*Fellow*), formerly a Senior Principal Scientific Officer in Charge of Flight Division, R.A.E., Bedford, is now with the British Joint Services Mission, Ministry of Supply Staff, Washington.

P. J. Duncton (*Associate Fellow*), formerly Assistant Chief Engineer, Atomics, at Fairey Aviation Co., Heston, is now Technical Manager (Atomics) of Fairey Aviation Ltd.

Sqdn. Ldr. J. C. Ellis (*Associate Fellow*), has been posted from the R.A.F. Leeming, to an appointment in the Directorate of Aircraft Engineering, Air Ministry.

R. J. Evans (*Associate Fellow*), formerly in the Department of Mechanical Engineering, Wolverhampton and Staffordshire College of Technology, is now Head of the Engineering Department, Burnley Municipal College.

Captain J. W. Gillespie (*Associate*), formerly with the Directorate of Aviation Safety is now an Executive to the Board of Directors at the Pressed Steel Company Ltd.

Commandant J. M. Grebil (*Associate*), recently Air Attaché to the French Embassy in London is now a Technical Assistant at the Circonscription Aeronautique Regionale de Toulouse.

Sqdn. Ldr. M. Greenwood (*Associate*), formerly Group Engineer of Headquarters No. 64(N) Group has been appointed Senior Technical Officer at the Air Electronics School, R.A.F. Hullavington.

W. M. Hargreaves (*Associate Fellow*), formerly Ministry of Transport and Civil Aviation Divisional Controller at Liverpool, is now Director, Control and Navigation (Operations) at Ministry Headquarters, Woburn Place.

Sqdn. Ldr. D. Hill (*Associate Fellow*), on completion of the Advanced Weapons Course at Henlow has joined the Armament Research and Development Establishment at Fort Halstead.

H. T. Howard (*Associate Fellow*), formerly a Senior Aerodynamicist with Auster Aircraft Ltd., is now with Blackburn Aircraft Ltd., Brough, in the Aerodynamics Department.

S. P. Hutton (*Associate Fellow*), formerly Head of Fluid Mechanics Division has been appointed Deputy Director of the National Engineering Laboratory (formerly the Mechanical Engineering Research Laboratory), East Kilbride.

N. W. Lewis (*Student*), formerly with Vickers-Armstrongs (Aircraft) Ltd., at Weybridge has been transferred to South Marston, Swindon.

K. J. Linder (*Student*), formerly a Graduate Apprentice with Vickers-Armstrongs (Aviation) Swindon, is now with the Solartron Electronic Group, Dorking.

J. McFarlane (*Associate*), formerly a Stressman with Auster Aircraft Ltd., is now a Draughtsman with Hunting Aircraft Ltd., at their London Design Office.

T. W. Mann (*Associate*), formerly Senior Engineer, Weapons Research Division, A. V. Roe and Co. Ltd., is now Production Superintendent (Electronics), Woodford.

Flight Lieutenant E. B. Monge (*Associate*), on completion of a Guided Weapons Course at Henlow has been posted to R.A.F. North Coates for guided weapon duties.

J. S. Nash (*Associate Fellow*), formerly an Assistant Engineer in the Mechanical Engineering Department of the Crown Agents, Millbank, is now an Engineer III at the Atomic Energy Research Establishment, Harwell.

W. E. Nixon (*Honorary Companion*) retires on 30th June from the Chairmanship and Managing Directorship of de Havilland Holdings Ltd., and also from his Chairmanships and Directorships of other de Havilland Companies.

B. R. Noton (*Associate Fellow*) has been appointed Technical Assistant to the Director of the Aeronautical Research Institute, Stockholm (F.F.A.) and will also conduct structural research as a Senior Scientific Officer.

D. G. Oliver (*Associate Fellow*), formerly Design Engineer with Avro Aircraft (Canada) Ltd., is now a Structural Design Engineer, Grumman Aircraft Engineering Corporation, New York.

W. E. Pearce (*Associate Fellow*), formerly Deputy Chief of London Design Office, de Havilland Aircraft Co., is now with Vickers-Armstrongs at Hurn Airport.

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The Twelfth Louis Blériot Lecture

The Griffon Aircraft and the Future of the Turbo-Ram-Jet Combination in the Propulsion of Supersonic Aeroplanes

by

GENERAL NOËL DAUM, A.F.R.Ae.S.
(Technical Director, Nord Aviation)

The Twelfth Louis Blériot Lecture, "The Griffon Aircraft and the Future of the Turbo-Ram-Jet Combination in the Propulsion of Supersonic Aeroplanes" was given by General Noël Daum, Technical Director, Nord Aviation, on 12th March 1959 at the Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1. Sir Arnold Hall, M.A., F.R.S., F.R.Ae.S., President of the Society, presided.

Before introducing the Lecturer, Sir Arnold presented the Society's Gold Medal, the highest award the Society can confer, which the Council had awarded to Monsieur Marcel Dassault and which they felt it would be particularly appropriate to present on this occasion—their annual joint meeting with the Association Française des Ingenieurs et Techniciens de l'Aéronautique (A.F.I.T.A.)

Born in 1892 Monsieur Dassault was one of the first students at the Ecole Superieure d'Aéronautique and had been in aviation almost ever since; he designed his first aeroplane in 1918 and the last to be designed by him was the Mirage IV—they had all heard of the Mirage III and IV and of the Mystere. Monsieur Dassault had, to some extent, embodied the spirit of French aviation; their British colleagues had always admired the wonderful flow of new ideas and new principles in all branches of engineering for which the French were noted.

Unfortunately, Monsieur Dassault was ill and unable to be present but he had great pleasure in presenting the medal to General Gallois, a colleague of Monsieur Dassault's who had come specially from France to receive it on his behalf.

Sir Arnold then welcomed the many distinguished visitors from France; they were particularly grateful to Madame Blériot for honouring them with her presence that night.

This year was the fiftieth anniversary of Monsieur Blériot's flight across the English Channel and before the Lecture they had a short film to show recalling that event.

Introducing the Lecturer, Sir Arnold referred to General Daum's career at the Centre d'Essai en Vol between 1935 and 1940, first as Head of the Engine Section, then Deputy Technical Director and then Director. From 1944 until 1947 he was Head of the Engine Section of the Service Technique de l'Aéronautique of the French Air Ministry and then returned to the Centre d'Essai en Vol for a year, again as Director. In 1938 he was appointed to the Direction Technique Industrielle which was primarily responsible for military aircraft, becoming director in 1953. In 1957 General Daum left the Service Technique to go into Industry and joined the Nord Aviation organisation as Technical Director. They could have no finer authority on the subject on which he was to lecture.

Courtesy of "Flight."

Madame Louis Blériot (*left*) who honoured the Society by attending the Twelfth Louis Blériot Lecture in this, the fiftieth anniversary of Blériot's flight across the Channel. On the right Madame Jarry.

FOLLOWING upon so many famous predecessors, it is a great honour for me to be called upon to give this Blériot lecture, which is one of the strongest manifestations of the friendship and the links which unite the aeronautical engineers of our two countries. I also feel some shyness, however, in coming to talk about engines to a country which has always shown such brilliance in the design and execution of aircraft power plants. I am emboldened to do it because what I want to talk about does not only relate to the field of engines, but equally to that of airframes.

I hope nevertheless that the engineers who are here tonight will find some interest in my account of the results obtained up to now by Nord Aviation in combining a turbo-jet with a ram-jet, the publication of which has only recently been authorised. I shall then sketch out Nord Aviation's views, based on these results, on certain applications to the propulsion of

FIGURE 1. The Griffon with turbo-ram-jet propulsion.

supersonic manned aircraft. My subject would not seem to be new, ram-jets having become familiar to everybody. Since the day when Lorin published his basic papers in 1913, many outstanding applications of ram-jets have been developed in various countries. As for turbo-jets, they have progressed with giant's strides since Air Commodore Whittle showed the way to all of us.

It is M. Leduc who was the first to have faith in the possibilities of the ram-jet for aircraft propulsion. With the faith of a pioneer, beginning before the war, he dedicated himself to the development of an airframe to demonstrate the validity of his thesis. His Leduc 10 and 16 were flown successfully, and one of them was presented in flight at the Le Bourget show in 1955. He followed these with the Leduc 21 and 22, which almost at the same time as the Griffon demonstrated in flight the feasibility of a well-balanced combination of a ram-jet designed to the scale of the aircraft, and a turbo-jet which gives the aircraft complete independence, particularly on landing and at low speeds. The difficulties which M. Leduc and his fellow-workers have had in surviving during and after the war, and the merit they have acquired in persevering in a path which many sceptics regarded as devoid of interest, are now common knowledge.

As regards Nord Aviation, the design of an aircraft making use of the same principles, the Griffon, was started in 1953. The firm has a division specialising in high speed aircraft, which, through the Gerfaut, already had had some experience of problems relating to supersonic flight. It also had a division devoted to the development of ram-jets, both for its own aircraft and for other aircraft or missile manufacturers. This background led the firm to undertake research into turbo-jet-ram-jet combinations, the need for which, it was thought, would necessarily become apparent as soon as manned aircraft were to exceed a Mach number of 2.

Although in our times the escape velocity from the earth's gravity has already been exceeded, and there is more and more talk of space flight, it is not rash to think that travel within the confines of our atmosphere will continue to occupy our attention for a long time yet. We may then, without any inferiority complex, still discuss air-breathing power plants which, in our opinion, may find their application in aircraft whose cruising speed modestly lies in the range between a Mach number of 2 and 4, according to type. This is not necessarily to say that these power plants are not suitable beyond the upper limit of the range quoted, but flight experience with the ram-jet up to the present, at Nord Aviation at least, does not yet extend to Mach numbers higher than 4. We certainly hope to exceed this figure in the near future, but in the present account we wish to base ourselves, as far as possible, only on the present state of the art.

Several designers of transport aircraft are already considering projects for supersonic machines which are to fly at Mach numbers of 2 or 3. Others are building bombers for a Mach number of 3. The propulsion problem is therefore with us today, and it is not premature to propose a system which, in our opinion, has a great future.

The combination of the ram-jet with the rocket, most often of the solid propellant type, has had many applications in guided weapons, British, American, and French. In most of these cases the accelerating engine or booster is jettisoned at a certain juncture, and from then on the ram-jet is the sole means of propulsion. These are cases, however, in which flight is characterised by high initial acceleration and no expectation of return, and it seems to me that under such conditions the rocket is indeed the right partner for the ram-jet.

For some civil or military operations however, which may require manned aircraft, the aeroplane cannot be subjected to excessive accelerations or high aerodynamic loads and, furthermore, provision must be made for landing. In such cases the combination of ram-jet and turbo-jet may offer decisive advantages. In what follows, we shall endeavour to bring out the possibilities raised by this combination in the formula which we advocate for manned aircraft, a formula which brings out in enhanced fashion and in a larger range of flight conditions the fundamental virtues of both types of engine. Though it be true that the ram-jet needs the turbo-jet at low speeds, we shall see that it is of very valuable help to the latter at high Mach numbers.

It may be useful to begin by recalling the problems which are posed by high speed flight with air-breathing engines, the manner in which these are being tackled,

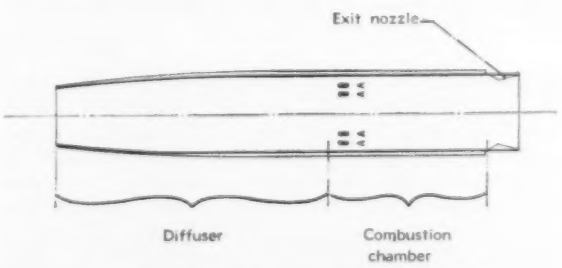


FIGURE 2. Ram-jet principle.

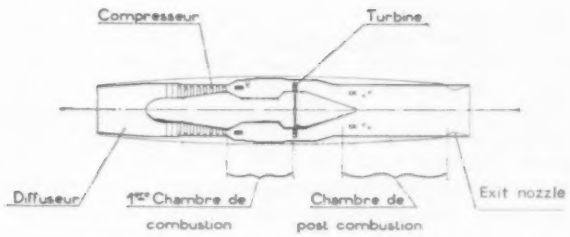


FIGURE 3. Turbo-jet principle, with reheat.

and the reasons why the composite power plant which is the object of our attention is the solution to be preferred. We shall then see how these ideas have found their first realisation in the original design of the Griffon II.

To clarify our terms we shall recall the principle of the orthodox ram-jet (Fig. 2), which is the simplest of the air-breathing engines. Thrust is characterised by a thrust coefficient very similar to the usual drag coefficient of aircraft. The engine has no moving parts. The fuel supply system requires, however, a source of power external to the engine, *e.g.* an air turbine.

The Turbo-Jet

Figure 3 shows the diagrammatic layout of the turbo-jet with reheat. To help comparison, we have shown the air intake. We are far from the days when the motor manufacturer had little interest in the installation problems which the aircraft designer had to face in fitting his engine to the airframe, and the air intake must be regarded as a component of the propulsion system. Even before reaching a Mach number of 3, the air intake bears the whole of the turbo-jet thrust, the engine beginning to exert some drag force on its attachments. It is seen that the turbo-jet with afterburner comprises the same elements as the ram-jet, plus a rotating assembly which represents an additional cycle, the essential function of which is to increase the pressure which must exist at the entry of the afterburner chamber.

The question must be raised whether, at increasing Mach numbers, the presence of this additional cycle (or dry part of the turbo-jet) is still beneficial to propulsion. From the standpoint of performance, the effect of increasing Mach number results from the following three considerations:

(*a*) The air temperature at the compressor entry increases rapidly with Mach number.
(*b*) The gas temperature at the turbine entry is limited to a given figure, which is a function of the state of art at the time.
(*c*) The speed of rotation of the machine cannot exceed a certain figure.

As is well known, these effects mean that as Mach number increases the turbo-jet pressure ratio deteriorates, and may even reduce to a value less than unity. The supplementary cycle thus becomes superfluous at first, and then harmful. The specific consumption becomes higher than it would be if the rotating parts were discarded.

If one endeavours to calculate this critical Mach number, assuming compressor and turbine efficiencies equal to those now being achieved at low air temperatures (which are already excellent), and assuming 1,000°C (1,800°F) as the limiting temperature at the turbine entry (a value already achieved, and assumed only by way of example), one finds that it is approximately $M=3{\cdot}3$; at this speed, the total delivery head to the afterburning combustion chamber is equal to the compressor entry pressure. Unfortunately, however, this calculation is based on a very optimistic view of reality. Apart from the fact that it is illusory to expect as good aerodynamic characteristics when hot as when cold, when expansion requirements do not call for high clearances which entail losses, allowance must be made for the fact that the problem is not to design an engine working at a given Mach number, but to cover a complete flight envelope. As regards the turbo-jet, the flight envelope may be defined by the extreme values taken in flight by the parameter $N/\sqrt{\theta}$, where N is the engine r.p.m. and θ is the air stagnation temperature at the compressor entry. For the majority of applications to high speed aircraft, these extreme values correspond on the one hand to a Mach number of 0·9 in the stratosphere, with $\theta=252°K=-21°C$ $(-5°F)$, and on the other hand to the maximum Mach number.

At $M=3$ $\theta=606°K=333°C=626°F.$
At $M=4$ $\theta=910°K=637°C=1{,}180°F.$

Taking 100 per cent as reference value at $M=0{\cdot}9$, $N/\sqrt{\theta}$ reduces to 65 per cent for $M=3$ and to 52 per cent for $M=4$, if the r.p.m. are kept constant. This range can of course be reduced by reducing the r.p.m. at low Mach numbers, but only at the cost of reducing thrust.

It is extremely difficult to achieve correct functioning of the compressor over such a wide range. An adequate margin against surging must be preserved when the air is cold, *i.e.* at low Mach numbers, while maintaining still acceptable values of efficiency when the air is hot, *i.e.* at high Mach numbers. Fig. 4 gives a typical example of compressor characteristics, with the turbine matching line shown. Various independent studies, relating to fixed geometry compressors with compression ratios

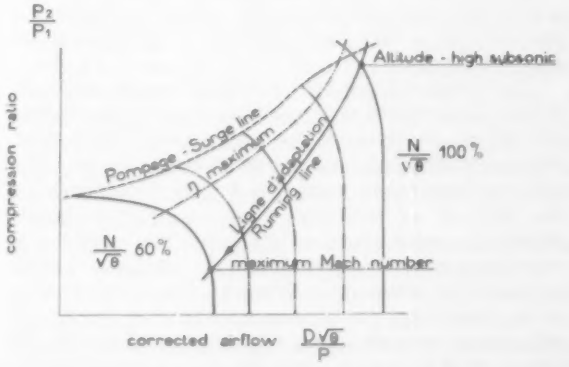


FIGURE 4. Typical running line with increasing Mach number.

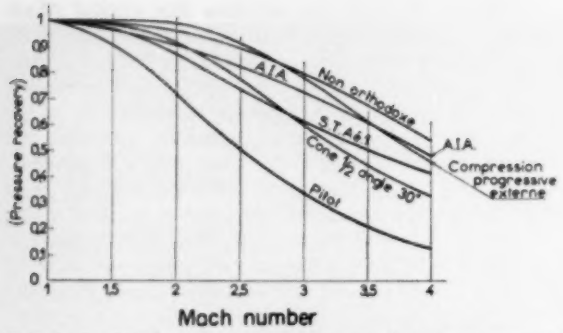


FIGURE 5. Maximum pressure recovery of different types of fixed geometry intakes compared with A.I.A. and S.T.Ae.1 efficiencies.

ranging between 3·5 and 8 at sea level, all lead to the following simple result: allowing a turbine entry temperature of the order of 1,000°C (1,800°F), all these turbo-jets cease to act as pressure amplifiers when the Mach number exceeds 2·7 or thereabouts. Beyond this value, the drop in total pressure is higher the higher the compression ratio at sea level. Raising the turbine temperature by 100°C (180°F) only increases the Mach number by about 0·25. It is also possible to bring in the complication of variable stator vanes, adjusted as a function of flight parameters; the critical Mach number can then reach or even slightly exceed 3. These improvements call for considerable technical effort, and are expensive in terms of weight and time.

So far however we have only examined the "pressure generator" function of the turbo-jet, which is of capital importance as regards specific consumption. We shall now consider the effect of the variation of $N/\sqrt{\theta}$ on the rate of air flow for this determines the dimensions of the engine and hence its weight. Fig. 4 shows that the flow coefficient decreases as $N/\sqrt{\theta}$ decreases, *i.e.* as the flight Mach number increases. This is essentially due to the fact that the Mach number at the compressor entry blades decreases because the blade tip speed remains constant and the air warms up. The Mach number is highest when cold, and cannot (on present-day engines) exceed a certain transonic value.

It may therefore be said that, as the flight Mach number increases, a given turbo-jet is less and less able to absorb a large rate of air flow. If it is to deliver a high thrust at a high Mach number, it will have to be larger and larger.

The variation in air flow with Mach number reminds us that the air intake is an essential organ of the propulsive system, and that it is necessary to study the mutual influence of the air intake and the turbo-jet proper. The flight performance of engines is usually calculated with the help of an arbitrary value for the air intake efficiency, a value whose variation with Mach number is sometimes officially defined (A.I.A. efficiency in the U.S.A., STAé efficiency in France). This kind of thing is very useful for comparison purposes. It is popular with motor manufacturers who like to show off the virtues of their engines, and also with airframe manufacturers, who find it helpful when it comes to producing

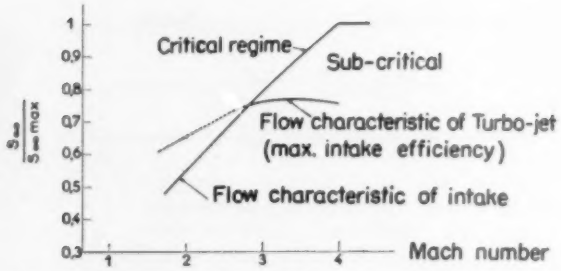


FIGURE 6. Operation of a conical-centrebody intake associated with a turbo-jet.

attractive "projects". The only person who could complain is the aerodynamicist who has the job of designing an air intake which really has these qualities in the whole flight envelope, without running to excessive complication. Still, it would seem that the stimulus is an effective one, since there is talk of increasing the "official" efficiencies, in the U.S.A. as well as in France. Fig. 5 shows the efficiencies, at their matching points, of various orthodox types of fixed geometry air intakes: Pitot (normal shock), plain cone with 30° half angle (oblique shock plus normal shock), isentropic (or more correctly with progressive external compression and normal shock wave), compared to official STAé No. 1 and A.I.A. efficiencies. There are orthodox intakes with supersonic internal compression which have better efficiencies, but they pose difficult starting problems. Other developments are in progress which we shall describe as unorthodox, but we shall not allow for them here.

The foregoing efficiency is not the only characteristic of an air intake, and is really achieved only under certain conditions. If the engine demand is excessive, an internal shock wave is formed, and the resulting pressure loss ensures that the engine gets a suitable volume flow. If on the contrary the demand is too small, the normal entry shock wave becomes detached in a forward direction, and its intersection with the boundary layer of the neighbouring surfaces triggers off surging or "buzz" of the air intake, which is a considerable danger. Fig. 6 shows the section at infinity of the flow tube which would have to enter the engine if the compression efficiency were that pertaining to a conical air intake of 30° half angle, taken by way of example. The figure also shows the section at infinity of the maximum flow tube which can actually enter the intake. It is seen that below the Mach number for which these two flows are matched, the engine demands too much air, and the intake will work with a swallowed shock wave, *i.e.* with loss in pressure; this is the "supercritical" régime. Above this Mach number, the intake is capable of supplying too much air, and the shock wave will become detached; this is the subcritical régime, with its danger of surging on the air intake. Unfortunately, more detailed analysis shows that this difficulty of flow matching at the air intake becomes worse as efficiency increases, or more precisely as external supersonic compression takes place with smaller losses. The use of a fixed geometry air intake thus leads to matching the intake section to the

maximum Mach number, and to accepting supercritical losses at lower Mach numbers. This is roughly equivalent to reducing the r.p.m. to retrieve matching, a solution which has the advantage of ensuring good flow conditions at the compressor entry. It is also possible to match to a lower Mach number, and to allow part of the air intake flow to divert outwards at higher Mach numbers. It is obvious that the resulting drag must be counted on the debit side in the balance sheet for the engine.

We have so far only discussed fixed geometry intakes. It is also possible to use variable air intakes, whose entry section would have to vary in such a manner as always to avoid working in the subcritical range. They usually comprise a major moving component which has to bear large loads, and whose position must be adjusted as a function of one or more measured parameters. Its shape itself is not variable, and this leads to some loss in compression efficiency. Furthermore, varying the entry section becomes insufficient if the range of Mach numbers is large, and one is compelled to combine a variable entry with a system allowing leakage flow, which system must also be adjustable; this is the by-pass arrangement. All this shows that, even with variable geometry, performance losses must be expected which are by no means negligible.

There is yet a third characteristic of air intakes, namely external drag. This is defined as the sum on the one hand of friction forces on the external cowling, and on the other hand of loads exerted by pressure increment or decrement acting both on the cowling itself and on the contours of the upstream flow tube which is going to enter the intake. At a given Mach number, the drag is the higher the smaller the section of the flow tube at infinity upstream, and the greater the deviation to which it is subjected before entering the diffuser.

Figure 7 gives the general trend of external drag for different types of air intakes, namely the Pitot type of which the efficiency is known to be small, the intake with conical centre body with 30° half angle, and an intake with progressive external compression having a high pressure recovery coefficient. Note that high efficiencies at high Mach numbers are associated with high drags at low Mach numbers.

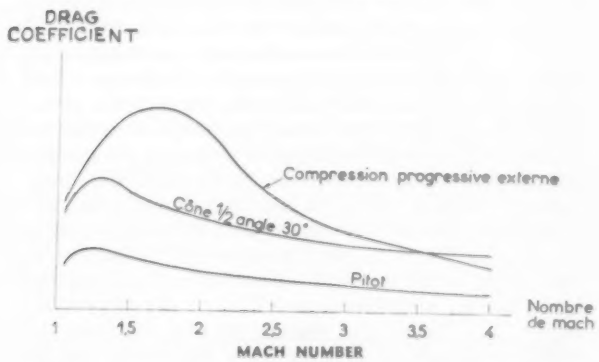


FIGURE 7. Comparison of external drags of different types of air intake.

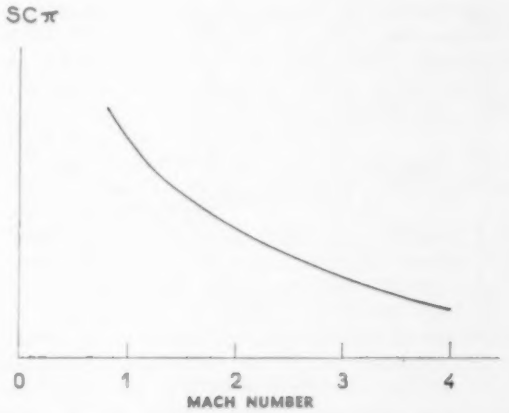


FIGURE 8. Typical variation of the thrust coefficient curve for a turbo-jet with afterburner (reheat).

The law of variation of the air flow of a turbo-jet is such that it should lead to relatively low external drags, particularly under transonic conditions. Unfortunately, however, it is difficult to find air intakes of orthodox types which are well matched to it, even with variable geometry.

In all the foregoing we have implicitly assumed that the turbo-jet exit nozzle was variable, so as to maintain the turbine entry temperature at a suitable value.

From all the considerations discussed, the result is that the net thrust of a turbo-jet follows a general trend with varying Mach number of the type shown in Fig. 8.

The Ram-Jet

Let us now revert to the ram-jet; we shall see that, while the state of affairs is somewhat better, it is not perfect either. Let us first look at the case when the exit nozzle throat is adjustable, as formerly. There is no longer any relatively low temperature limitation imposed by a turbine, neither is there any compressor whose limiting speed prescribes a law to the intake flow. Variation of the nozzle throat section now directly affects air flow at the entry, and allows the intake to work permanently under matched conditions. It is the air intake that determines the qualities of a ram-jet. If an intake is chosen which has a high pressure recovery ratio at high Mach numbers, there results an engine which is incomparable at high Mach numbers but poor at lower ones, when its external drag will be high. If good characteristics are desired at low Mach numbers one must be less demanding as regards higher ones. The laws followed by the net thrust coefficients, *i.e.* with allowance for external drag, will differ noticeably in the different cases.

Figure 9 graphically portrays these conclusions. The intermediate curve is a good compromise.

It is however also of interest to consider what happens when the exit nozzle throat is kept constant. If a fixed gas temperature at the ram-jet exit is deliberately postulated, there occurs a phenomenon which is exactly the opposite of what happens in matching a turbo-jet to

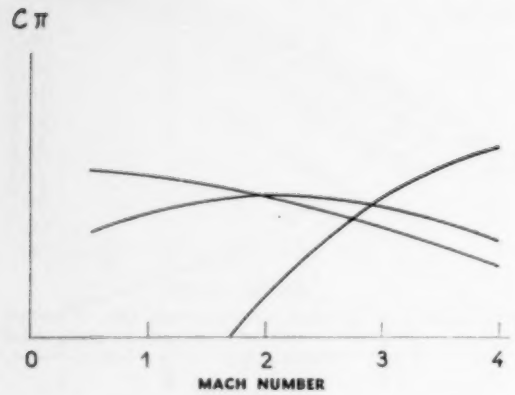


FIGURE 9. Typical examples of net thrust coefficients for various ram-jets.

a fixed air intake. Beyond the Mach number chosen for air flow matching, the ram-jet air intake works under supercritical conditions, *i.e.* with some loss, while below that Mach number subcritical conditions obtain, with risk of buzz, though much less severely than in the case of the turbo-jet, surging of the air intake being essentially linked to the intensity of the normal shock, which decreases together with Mach number. Performance is still reduced however. The mismatching effect is the more marked the lower the efficiency of the air intake. With an air intake of the progressive external compression type, matching remains correct within the range of Mach numbers for which compression is truly isentropic.

The Turbo-Ram-Jet Combination

We can now say something about the combined turbo-jet-ram-jet. From what we have just seen, one might be tempted to add the thrust coefficients of a ram-jet and a turbo-jet with the aim of achieving any desired variation with Mach number. One might for instance choose a turbo-jet having high thrust at low Mach number and hence having a high compression ratio, and a ram-jet matched to high Mach numbers and having a high efficiency intake, and add up the thrusts. It is however possible to do much better than this. In the solution advocated by Nord Aviation, there is a common air intake. If the ram-jet exit nozzle is variable, the compressor no longer imposes its law on the air intake, and the turbo-jet can take full advantage of the high air intake efficiency which suits the ram-jet.

The air flow requirements of the turbo-jet and the ram-jet, which are characterised respectively by the Mach number at the compressor entry and the Mach number at the combustion chamber entry, vary in inverse directions as the flight Mach number varies, and because of this it is always possible to find a type of fixed air intake with a good efficiency, for which matching to the total air flow will remain correct within a large range, allowing, if need be, an acceptable variation of the exit nozzle throat section.

From the combination we have just discussed we may expect not only the sum of the thrust of a turbo-jet and that of a ram-jet, but the sum of the thrust of a turbo-jet without intake losses and that of a well matched ram-jet, while avoiding the complication of having two variable geometry intake systems. Even if, in order to get an optimum figure for net thrust or specific fuel consumption, one were led to using variable geometry, the air intake problem would still be considerably eased by the fact that the variation in the total air flow coefficient would be much less than in the case of a turbo-jet or ram-jet taken separately.

Conversely, designing for minimum weight could lead us to accept sacrifices in performance, and a turbo-ram-jet having fixed intake and exit geometry is quite feasible with acceptable matching provided the cruise Mach number is not too high ($M<3$); this is the case with the Griffon. A common exit also has advantages, but these are more difficult to bring out, due to the simultaneous variation in the mass flow of a turbo-jet and its total pressure amplification ratio.

Before probing further into the characteristics of the turbo-ram-jet, let us consider what are the desirable characteristics which we wish to have in an engine intended for a very high speed aeroplane.

Let us begin with cruising flight at the maximum Mach number, which we shall assume to take place according to the Breguet type of trajectory, for which the distance covered is given by the well-known formula

$$R = \text{Constant} \times \frac{V}{C_s} \frac{L}{D} \log \frac{W_1}{W_2}$$

We see that the specific consumption C_s is the fundamental characteristic of the power plant. We have seen that as soon as the Mach number reaches 2·7 to 3 according to the type of turbo-jet, the specific consumption of the ram-jet becomes lower than that of the turbo-jet. Allowing for air intake difficulties, these figures are reduced to 2·5 and 2·8.

The fact should be stressed here that as soon as the zone around Mach number 2·7 is reached, the specific consumption is essentially a function of the intake characteristics. This is obvious as regards the ram-jet, but the turbo-jet is in the same position since by then it has lost its ability to amplify pressure. It could almost be said that it is the aerodynamicist concerned with the air intake who could give us the best information on specific consumption. As a rough guide we may say that with a good air intake of the orthodox kind, at a Mach number of 2·7, the specific consumption is of the order of 2·3 lb./lb./hour for the turbo-jet as well as for the ram-jet. When the Mach number decreases, the specific consumption of the turbo-jet decreases, while that of the ram-jet increases. Thus at a Mach number of 2 the ram-jet would achieve 2·5, the turbo-jet 2·20, the turbo-ram-jet about 2·35. At a Mach number of 1·5 the ram-jet would rise to 2·8, the turbo-jet would drop to 2, and the turbo-ram-jet would stay at 2·35. At Mach numbers above 2·7, the specific consumption of the turbo-jet would progressively increase while that of the ram-jet would decrease slightly or stay constant. Any attempt at greater accuracy would be illusory, the essential factor

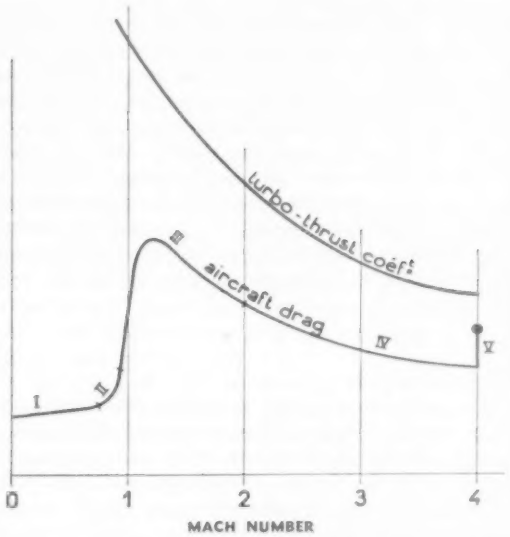


FIGURE 10. Example of comparison of the net thrust coefficient of a turbo-jet with the drag coefficient of an aircraft during acceleration and climb.

being the manner in which the air intake problem has been tackled in the two cases. We shall presently, when speaking about the Griffon, give a few figures of fuel consumption as measured in flight on an aircraft whose conception dates back to before 1955.

It should be noted here that for the same weight of fuel, using a lighter engine allows a better value of W_1/W_2 to be achieved, and hence gives a longer range for the same specific consumption.

For that part of the flight which corresponds to acceleration and climb, it is possible to imagine many different flight patterns. Fortunately, owing to the presence of the transonic drag hump and to structural strength limitations on aerodynamic loads, most high speed aircraft projects are based on climb programmes showing but little variation; these may be decomposed as follows:—

1. Acceleration at very low altitude up to about $M = 0{\cdot}9$.
2. Climb at constant $M = 0{\cdot}9$ up to a relatively high altitude, but always less than 36,000 ft.
3. Acceleration at constant altitude or in slight climb up to the point when maximum aerodynamic loads allowed by structural strength are reached. Loading may be expressed in terms of equivalent airspeed, say 700 knots, or by some nearly equivalent parameter.
4. Climb at constant aerodynamic loading up to the maximum Mach number.
5. Climb at maximum Mach number up to the cruise altitude.

The drag curve of the aircraft (not including power plant drag) can then be drawn along the whole of this trajectory, as a function of Mach number. Fig. 10 gives a typical shape for this curve. The "net thrust" coefficient of the power plant must at all points be higher than the drag if the aircraft is to climb and accelerate. If the thrust is chosen at too high a value, the engine may be too large and hence too heavy. If the excess of thrust is too small, the fuel consumption may suffer owing to long duration of the climb.

An optimisation study is therefore necessary, if it is the case that the size of the engine is in fact determined by this part of the flight.

Let us examine the case of the turbo-jet alone. The trend of variation of its thrust coefficient is very close to that of the aircraft drag coefficient. Within a large range, the excess of thrust coefficient over drag coefficient is very roughly proportional to the latter. The size of the turbo-jet may be determined either by conditions at the end of the climb at cruising Mach number, or by optimisation of the climb and cruise portions taken together. The first case will result if the cruise Mach number is very high and adequate margin for manoeuvring is required, or again if the length of the mission is such as to demand cruising at relatively weak mixture, corresponding to the minimum specific consumption. The corresponding engine will then have considerable excess of thrust in the transonic range. It will be large and heavy.

In the second case, optimisation is based on the minimum weight of power plant plus fuel required for accelerating climb. In some calculations which have been made, this optimisation has led to the conclusion that the excess of thrust must be of the order of magnitude of the drag. The thrust margin in the transonic range is thus very large, and again in this case a very large engine must be chosen (Fig. 10).

In both cases there is super-abundant thrust at take-off if the range is not exceedingly long.

With the turbo-ram-jet, we have an additional variable which allows us to achieve an almost arbitrary law of variation of the thrust coefficient, this variable being the proportion of ram-jet added to the turbo-jet. Again the type of ram-jet can be varied. It is then possible in particular to achieve a law such that the excess of thrust

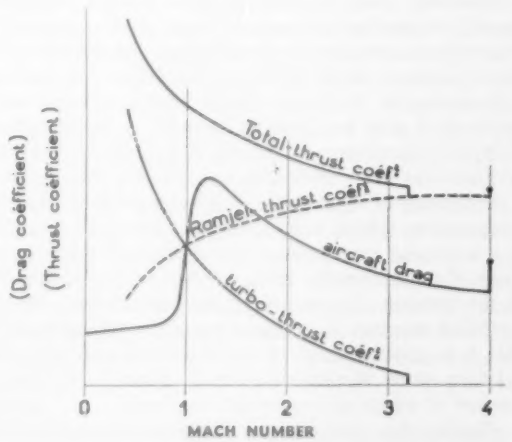


FIGURE 11. Example of comparison of the net thrust coefficient of a turbo-ram-jet combination with the drag coefficient of an aircraft during acceleration and climb.

should be large in the high supersonic range and small in the transonic range. This means that the turbo-jet will be small (Fig. 11).

The ram-jet's high specific consumption below $M = 2{\cdot}5$ will be largely compensated by the small duration of the acceleration in the definitely supersonic range. The total weight of power plant and fuel during the climb will be less than with the large turbo-jet. In any event, there will be a large thrust margin under cruise conditions, and this allows the richness to be reduced during the cruise to a value corresponding to minimum specific consumption.

The aircraft has good aerodynamic characteristics in transonic flight ("wasp waist" or "area rule"), or more precisely if the ratio of maximum drag coefficient to cruising drag coefficient is not too high, one may be tempted to decrease the proportion of turbo-jet still further. One must then make sure that the sea level thrust is sufficient for take-off.

In all the foregoing we have hardly mentioned the most fundamental virtue of the ram-jet, and the one which justifies its use, alone or in alliance with the turbo-jet, even under conditions in which it is very much inferior thermodynamically to the turbo-jet: that is its lightness. This lightness, which is noticeable even under subsonic conditions, is due to the total absence of moving parts, to the low value of loads due to internal pressures (these loads vary in the same way as the aerodynamic loading of the aircraft), and to the fact that hot regions are cooled by air at a temperature equal to the stagnation temperature of ambient air, which is the lowest value obtainable. Note also that if the range is not too large, important simplifications may be made to the turbo-ram-jet with a view to lightening it. We shall see an example of this in the Griffon.

The turbo-ram-jet has other virtues which thermodynamic analysis has not shown.

Firstly, it is by definition flexible, so that during manufacture or even after the first few flights, its characteristics can be modified to cope either with variation in the drag of the aircraft, or with changes in the specification.

Secondly, there is no need to have a turbo-jet capable of working at the maximum Mach number. It is possible to use an existing engine designed for a lower Mach number. Such an engine would be switched off on reaching its design maximum Mach number, and then kept in slow windmilling in order to maintain flow of liquids in pipes and at bearings. Certain minor modifications must obviously be made for this purpose.

This kind of operation is made easy by the coaxial arrangement, which results in the turbo-jet remaining in a subsonic environment, the Mach number in the plane of the air intake being of the order of 0·4 to 0·5 on the average. In the exit plane around the turbo-jet the Mach number is of the same order of magnitude. This fact greatly eases the problem of relighting the turbo-jet when the aircraft comes down to the Mach number at which the turbo-jet can work.

Finally, the period required for the development of a ram-jet around a turbo-jet is surprisingly short as soon as some experience has been acquired through previous tests.

Arrangements different from ours have been investigated by some other engine manufacturers. Most of these are not true turbo-jet-ram-jet combinations allowing harmonious coexistence of the two partners, and using their complementary properties to the best advantage. This is the case for instance of the "by-pass" engine, which arises from the natural desire to enable an existing afterburner chamber to survive at a higher Mach number. Besides being rather cumbersome and entailing a transition phase, the crossing of which is rather tricky in either direction, this solution disregards the fundamental virtue of the ram-jet, which is its lightness.

The Griffon

We shall now end this somewhat arid part of the lecture, during which we have only been able to discuss a small part of the problems raised in combining the turbo-jet with the ram-jet. We shall encounter a few more of them in the ensuing part, which is more specially devoted to the Griffon II.

For many years, the French Air Ministry has been interested in the possibilities of marrying the turbo-jet to the ram-jet, the development of which had been advancing under the impulsion of M. Leduc and some other development establishments. It was only at the end of 1953 however that the decision was taken to order an aircraft propelled by a combined engine from our company, which had been working on the ram-jet for some years.

There were to be two stages, the first being orthodox turbo-jet propulsion using a SNECMA ATAR F engine with afterburner and no ram-jet, and the second in which this engine was to be replaced by a turbo-ram-jet designed around the SNECMA ATAR E3 dry turbo-jet.

Preliminary work on the engine had already begun before this. Early in 1953 it had been decided to build a small turbo-ram-jet around the Turbomeca Palas engine. Pending its completion, the firm built a functional scale model of it, based on a combustion chamber for the Ariel helicopter, with the object of doing preliminary work on the interaction of the two engines under static and low speed conditions. This model is shown in Fig. 12. Compression was effected by an independent compressor on a by-pass circuit. This experimental work showed up thrust losses at take-off, and allowed development of methods of reducing these losses.

In the course of the same year development work

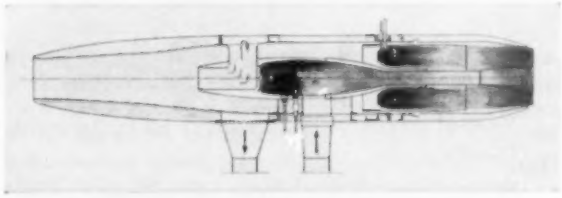


FIGURE 12. Working model to simulate the turbo-ram-jet combination with an "Ariel" combination chamber for tests at Gatines.

began on the Palas based turbo-ram-jet working in a free stream on the Gatines test bench. This is shown in Fig. 13. In 1945 tests were continued in the large Modane wind tunnel up to $M=0{\cdot}8$. The first tests showed up an interaction effect between the two engines which led to surging of the Palas, of a rather unusual type, with a very rapid upward runaway of the temperature at the turbine entry.

In 1955 means of preventing the above trouble had been found, although the explanation of the effect was not entirely satisfactory. Meanwhile, work was proceeding on the design and construction of a full scale prototype power plant, similar to that intended for the aircraft, and differing from it only in that it was somewhat more sturdily built.

In the spring of 1956 the decision was taken to fit the second Griffon directly with the turbo-ram-jet without going through the afterburner phase. This decision was motivated by the excellent flight test results obtained with the Griffon I, which was being used to develop the airframe. Development work had been fairly short, thanks to the experience which the firm had had already with delta winged aircraft, in particular the Gerfaut II, which incidentally was to hold the world record for climb, over quite a long period.

During the same spring, tests on the Atar E3 experimental turbo-ram-jet were begun in the large wind tunnel at Modane. Development was rapid, both as regards combustion and as regards fuel supply and control equipment. The best arrangement was chosen to reduce losses at take-off. Investigation of the combined plant with the ram-jet switched off enabled the value of the "cold" drag of the ram-jet to be determined. In November 1956 endurance tests were carried out at Modane on the flying version of the Atar E3 turbo-ram-jet, identical in every respect to that intended for the aircraft.

At the end of January 1957 the Griffon II made its first flight. In April the ram-jet was lit in flight for the first time. In May the speed of sound was exceeded. In June several supersonic flights were made up to $M=1{\cdot}3$. The Mach number was then progressively increased until December, when the aircraft achieved $M=1{\cdot}85$ at an altitude of 42,000 ft. There was still a large surplus thrust, giving a rate of climb of 28,000 ft./minute. Further advance in Mach number was very slow as the turbo-jet limitations were being approached. Nevertheless, since October 1958 flights in the neighbourhood of $M=2$ have almost become a matter of routine, the turbo-jet being throttled back from $M=1{\cdot}8$ in order to conserve its life. It must be acknowledged that so far this turbo-jet has valiantly stood up to all the onslaughts of heat, and incidentally that its reliability has been excellent in every respect.

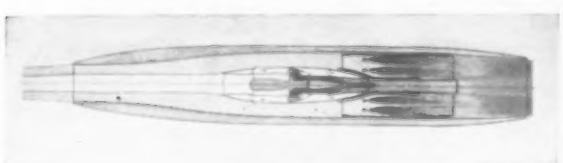


FIGURE 13. Combination of ram-jet and "Palas" turbo-jet configuration for tests at Gatines and Modane.

The aircraft has by now made more than 200 flights. One of its best performances has been $M=2{\cdot}1$ at 61,000 ft., while still accelerating and climbing slightly. Thermal limitations on the airframe have so far prevented us from going any further.

The aircraft weighs 15,000 lb. all up, of which the power plant accounts for 3,740 lb. fully equipped, including ram-jet structure, ram-jet accessories (ignition, control, fuel supply, regulation, and so on) and the afterpart of the fuselage, which forms a shell around the ram-jet. The latter has a diameter of 4·5 ft., which at a Mach number of 2 gives more than 80 per cent of the total thrust, which is 9,200 lb. at around 50,000 ft. and 5,500 lb. at around 60,000 ft.

Besides the firm's pilots, several others have flown the aircraft, in particular foreign pilots. All have expressed their satisfaction with the good behaviour of the power plant, and with the confidence which it inspires by virtue of the fact that it gives an impression of smoothness, which is not achieved with afterburning. All of them have also been impressed by the ease with which the aircraft can be manoeuvred in a supersonic turn at high "g", the aircraft continuing to accelerate none the less.

Incidentally, it is this particular feature which has recently enabled the Griffon to obtain the world speed record for the 100 km. closed circuit (1,640 kms./hr., 1,030 m.p.h., 24th February). This record has shown up not only the aircraft's speed potential and its aerodynamic qualities, but also, and even more strongly, its ability to maintain a very high thrust in the turn, which enables it to accelerate where orthodox aircraft have to decelerate. Note particularly that, contrary to a fairly widespread notion, the ram-jet may be made completely insensitive to the effects of incidence. As for the turbo-jet, its position inside the ram-jet makes it incapable of knowing whether or not there is any change in incidence.

Among other items noted by the pilots, mention may be made of the fact that the ram-jet starts and works satisfactorily within a wide range of conditions. There is no unfavourable interaction between the two types of engines; even deliberately provoked flame-out of the ram-jet leaves the turbo-jet unconcerned. Moreover, the loss of thrust at take-off is distinctly less than that experienced with orthodox aircraft propelled by turbo-jet only.

The flexibility of the ram-jet has been demonstrated, as it has been possible, thanks to a distributed injection system, to make the mixture strength vary from 0·15 to 0·85. Many flights have been devoted to the development of good control characteristics for the ram-jet; these characteristics are important for a manned aircraft, while there has been no need to place the same degree of emphasis on them in all the applications to guided weapons.

Here are a few results concerning the power plant: Thrust loss at take-off is distinctly less than that experienced with an orthodox aircraft driven by a plain turbo-jet. The ram-jet lights and works satisfactorily

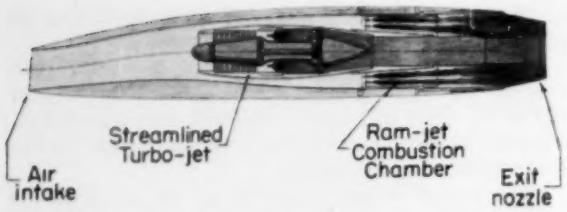


FIGURE 14. Diagram of operation of the turbo-ram-jet combination.

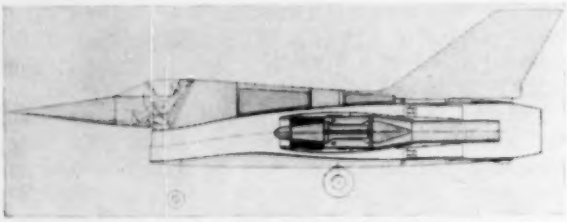


FIGURE 15. Layout of the Griffon aeroplane.

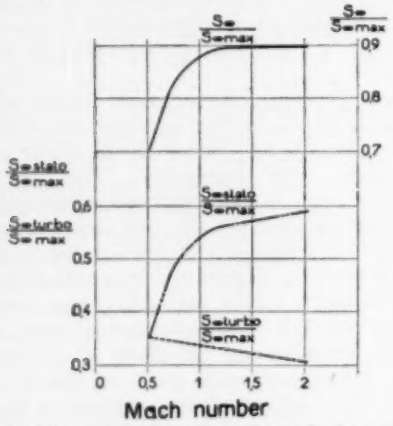


FIGURE 16. The curves show how the turbo-jet and ram-jet flows vary in opposite senses with Mach number, while the total flow remains practically constant at supersonic speeds.

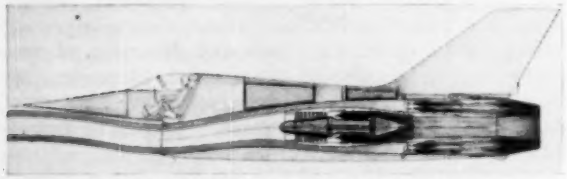


FIGURE 17. Distribution of flows in the turbo-ram-jet at subsonic speeds.

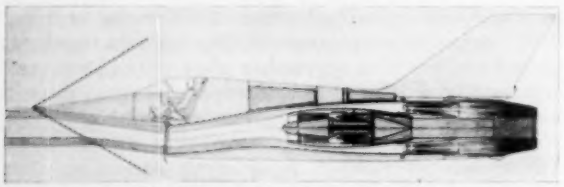


FIGURE 18. Distributon of flows in the turbo-ram-jet at supersonic speeds. Note constriction of turbo-jet flow.

within a wide range. The power plant is completely insensitive to incidence effects. There is no unfavourable interaction between the two types of engine; even if the ram-jet is deliberately caused to flame-out the turbo-jet remains unconcerned.

Figures 14 to 26 show various aspects of the turbo-ram-jet combination and typical performance curves.

I would like to stress that, while the turbo-ram-jet has enabled the Griffon to fly regularly at around a Mach number of 2 at 60,000 ft., this result has been obtained without difficulty with a standard Atar 101 E3 turbo-jet of 7,700 lb. static thrust, which had not been designed to operate at such high Mach numbers. Higher speeds are possible, there being a large surplus thrust; unfortunately however we cannot take advantage of this, owing to kinetic heating limitations.

If the same performance was to have been obtained with a plain turbo-jet with reheat, recourse would have had to be made to the most recent engines or to some in the course of development (it was impossible since the Griffon was conceived in 1953-54). Recourse would also have had to be made to variable geometry, while the Griffon air intake is of the Pitot type, and there is no variable geometry, either at the intake, or at the ram-jet and turbo-jet exits. The thrust required to obtain the performance actually achieved, which is equivalent to more than three times that of an Atar with afterburning, has thus been obtained with a much smaller installed weight, and with development and manufacturing costs much lower than those of modern jet engines having the same characteristics.

Future Applications

Following the results obtained with the Griffon, we are presently continuing to investigate applications of this type of power plant to more advanced aircraft of different types. From the point of view of the aircraft designer, these applications may be grouped into two broad categories, which we are putting forward to our colleagues for aircraft designed to fly at above a Mach number of 2. These are:

(*i*) a power plant integrated with the aircraft structure; or

(*ii*) an independent power plant which may be used in the same manner as pod-mounted turbo-jets.

The first of these solutions allows very light structural designs, but the interdependence of engine and aircraft problems is such that very close co-operation is required between aircraft and engine designers, at least as regards the ram-jet. Thus in the case of the Griffon, which is the prototype of this solution, the

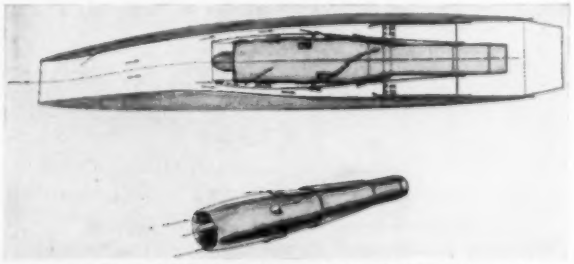


FIGURE 19. Ventilation diagram for turbo-jet and ram-jet.

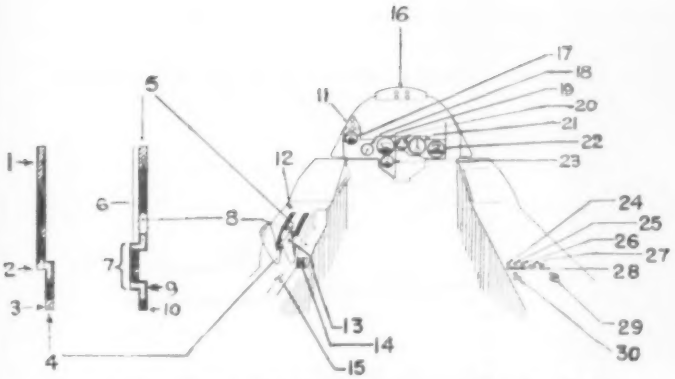


FIGURE 20. Engine controls and instrumentation in pilot's cockpit for the two engines. The turbo-jet and the ram-jet are controlled independently by two separate levers.

1. Full throttle
2. Idling
3. Stop
4. Turbo-jet control
5. Ram-jet control
6. Ram-jet operation
7. Connection of fuel system
8. Throttle slides
9. Light pilot flames
10. Stop
11. Visual indicators—ancillary services
12. Fuel/Air ratio control
13. Exterior of throttle slides
14. Flame-out ram-jet
15. Flame-out turbo-jet
16. Warning lights: turbo- and ram-jet overheating and fire
17. Fuel pressure
18. Fuel/air ratio indicator
19. Jet pipe temperature
20. Oil pressure and temperature
21. Tachometer
22. Flowmeter
23. Hydraulic pressure
24. Turbo-ram-jet starter safety switch
25. B.P. pump
26. Ignition ventilation
27. Starter } turbo-jet
28. Re-light }
29. Ram-jet cut-out
30. Servo-controls

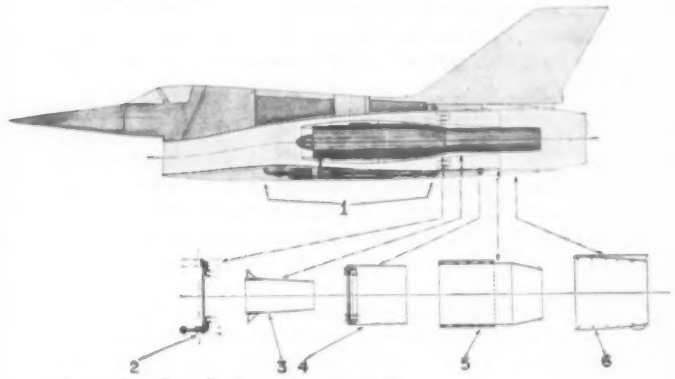


FIGURE 21. Ram-jet structure; rear part:

1. Fuel supply and control compartment
2. Fuel distributor
3. Internal protector annulus
4. Protective annulus with fuel jets and flame stabiliser
5. Combustion chamber exit at rear with nozzle
6. Rear part of fuselage

FIGURE 22. Weight analysis of turbo-ram-jet combination:

i. Turbo-jet assembly including: ATAR 101 E.3 weighing 1940 lb. plus jet pipe and cowling		2445 lb.
ii. Ram-jet structural assembly	958 lb.	
iii. Ram-jet equipment including: Ignition control, fuel supply, regulation	181 lb.	
Total weight RAM-JET	1139 lb.	
Total weight TURBO-RAM-JET		3584 lb.
iv. Rear fuselage section (containing the ram-jet)		161 lb.
TOTAL WEIGHT		3745 lb.

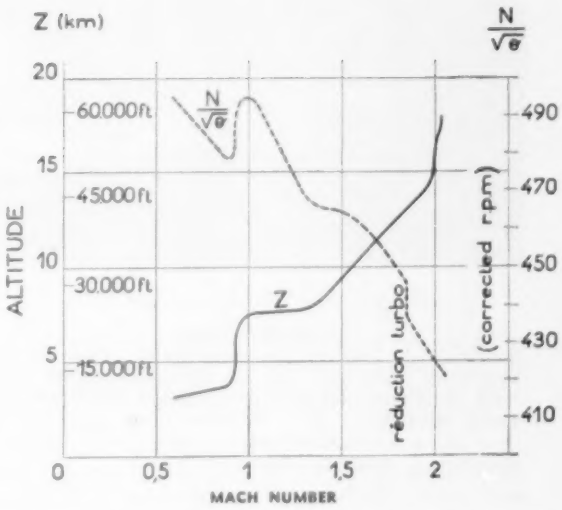


FIGURE 23. Flight No. 145. Variation of altitude with Mach number. These curves show a typical climb programme for a flight. Also shown is the value of $N/\sqrt{\theta}$, the equivalent speed coefficient for the turbo-jet.

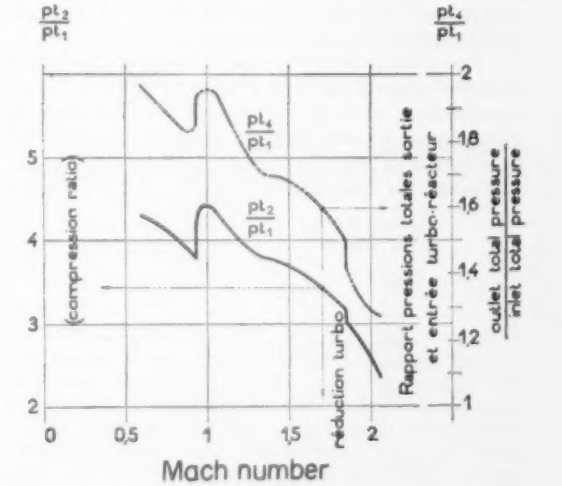


FIGURE 24. Flight No. 145. Variation of turbo-jet characteristics during flight. Curves of compressor compression ratio $(pt_2)/(pt_1)$ and total pressure amplification ratio $(pt_4)/(pt_1)$ for the turbo-jet. Note how they decrease with increasing Mach number.

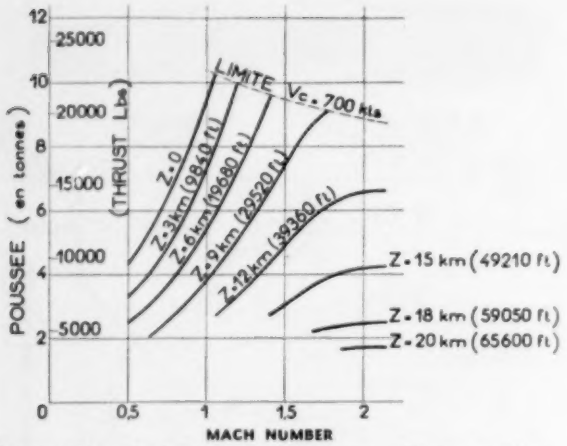

POUSSEE (en tonnes)
(THRUST Lbs)
MACH NUMBER
LIMITE Vc = 700 kts
Z = 0
Z = 3 km (9840 ft)
Z = 6 km (19680 ft)
Z = 9 km (29520 ft)
Z = 12 km (39360 ft)
Z = 15 km (49210 ft)
Z = 18 km (59050 ft)
Z = 20 km (65600 ft)

FIGURE 25(*a*). Turbo-ram-jet thrust curves. These are calculated from flight tests, and correspond to a relatively low value of mixture richness (or equivalence ratio) which will soon be increased.

Note: { 5,000 lb. thrust. 60,000 ft. altitude. $M=2$.

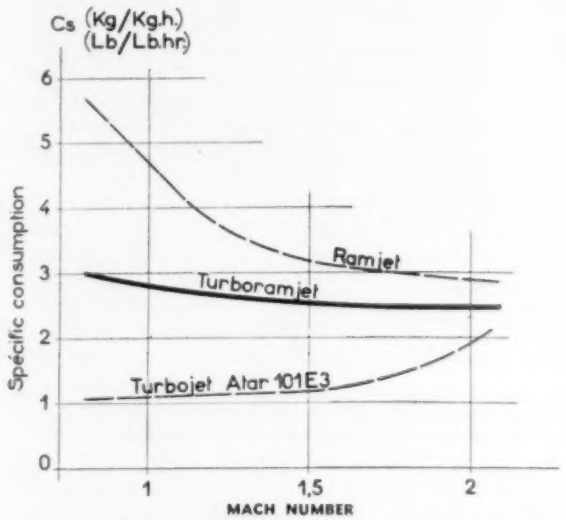


FIGURE 25(*b*). Specific consumption curves as a function of Mach number, as measured in flight. The thrust is equivalent to that of three Atar G (with afterburning).

interaction between air flows around the intake and around the rest of the structure has (in particular) enabled the transonic zone to be crossed without any longitudinal perturbation, thanks to a judicious disposition of the parts concerned. This is one of the very few cases where such insensitiveness has been achieved without recourse to autostabilising devices. Conversely, the proper functioning of the ram-jet, and particularly proper combustion in the ram-jet chamber, is in close dependence on perturbations set up in the internal flow by the rest of the airframe.

The same need for co-operation between aircraft and engine designers arises in respect of control and supply installations, and also in respect of the mounting of combustion organs such as chamber, cooling sleeves, injectors, and flame barriers.

Based on this type of layout, we have designed a

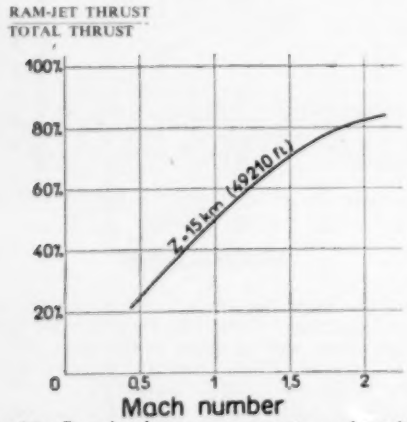


FIGURE 26. Ram-jet thrust as a percentage of total thrust.

Turbo-jet:—

$N=8{,}400$ r.p.m. at $M<1{\cdot}8$
$N=8{,}200$ r.p.m. at $M\geqslant 1{\cdot}8$

Griffon derivative with a turbo-ram-jet based on a more advanced turbo-jet. The qualities of this power plant are such that we have been able to announce with absolute confidence a performance of over $M=3$ at altitudes between 66,000 and 80,000 ft., and a hitherto unapproached degree of manoeuvrability at very high altitude.

In the same spirit, we have also investigated the combination of one or more turbo-jets with a flat ram-jet. This arrangement is feasible, and for large aircraft it allows the air intakes to be located under the wing, and even, if necessary, a relatively slight adjustment of intakes and exits. It is also capable of leading to substantial improvement in the lift to drag ratio, and hence in range.

With the second solution, the turbo-jet and ram-jet make up an independent nacelle which, if regulation is required, could include the intake and exit control equipment.

A design of this type now under investigation finds an interesting application as a means of increasing the speed of very large transport aircraft to supersonic values in the cruise. Here again the low weight of the power plant, which the ram-jet alone makes possible, gives a very clear advantage to the combined engine, while at very high Mach numbers this advantage may be further increased by a substantial improvement in the specific consumption.

Conclusions

In conclusion, I would like to say that as a result of all the work carried out at Nord Aviation on the applications of the turbo-ram-jet, and on comparisons with other means of propulsion, we may sum up the advantages offered by the combination engine to the aircraft designer, as follows:

For Mach numbers between 2 and 4, only air-breath-

FIGURE 27. The Nord-Aviation Griffon 02 with turbo-ram-jet propulsion.

ing engines are worth considering, owing to the very high specific consumptions of alternative types, and also owing to difficulties regarding some of their fuels (I am thinking of liquid fuel rockets).

From the comparison between the plain turbo-jet and the combined engine, the superiority of the latter is due essentially to its enormous specific thrust, which gives a saving of at least 30 per cent on the weight of the equipped power plant, in the case of large aircraft. This saving is the more important the higher the thrust required in cruising flight, in the neighbourhood of the maximum lift to drag ratio. It may be used to increase either range or payload, to such an extent that it may be stated that for a given take-off weight, using a combination engine allows either

(*a*) an increase in range of 20 per cent

or (*b*) doubling the payload

in the case of a large long range aircraft.

To the above advantage is added the very great simplicity of the ram-jet for very high powers, and the possibility of using an engine of small size, and hence much less expensive in terms of development, manufacture, maintenance, and so on.

Several solutions have been or are being considered with the object of associating the ram-jet with the turbo-jet, and we are acquainted with various investigations now in progress. While we do not of course claim to have developed the only valid solution, we do think that the arrangement adopted on the Griffon has virtues which, we hope, ensure a great future for it, while some other arrangements which call for rather complicated and fearsome flaps or variable geometries must have some development difficulties in store. Our work on the Griffon has occupied several years, and has compelled us to define our theory on the combination of the two engines, or to make specific equipments. We should be very happy to give the benefit of our experience to others, as we are convinced that this realm of flight above a Mach number of 2, which seems so fearsome and bestrewn with difficulties today, will be a reality tomorrow, as is the present-day flying of fighters and bombers at a Mach number of 2 and of trans-Atlantic air liners at a Mach number of 0·9 which, I think, no one would have dared foretell with any confidence only fifteen years ago.

ACKNOWLEDGMENT

The lecturer wishes to acknowledge the assistance of Monsieur Gozlan and Monsieur Flamand in the preparation of this paper.

VOTE OF THANKS

A vote of thanks to the Lecturer was proposed by Lord Brabazon of Tara, P.C., G.B.E., M.C., Hon.F.R.Ae.S.

Lord Brabazon: The Blériot Memorial Lectures had always been of a high order and this twelfth lecture lived up to the tradition. They had seen the old film taken 50 years ago; he belonged to that vintage; they were not very good at cinematography in those days, but there was nothing else wrong with them and he well remembered walking along in Paris with Wilbur Wright and asking him, "Will you design for me an aeroplane that will go 100 miles an hour?"—a very imaginative project he thought for that time. Wilbur Wright's reply was remarkable:—"Certainly, if you will get me the engine necessary." So it was today, and all through fifty years of flight, they had always been looking for the engine necessary, and they were looking for it that night.

The French in the early days had dominated flight by virtue of their remarkable engines. The "Antoinette" by Levasseur, a V.8—with, would they believe it, in those days—fuel injection. It was a remarkable power plant and most unreliable. And then Blériot's "Anzani" three cylinder engine. He would not extol the virtues of that because it was a poor engine, but it did its job, largely due to the British climate which, at a critical moment when the engine was about to overheat, poured one of the national downpours of rain upon the engine. But, of course, it was the seven-cylinder air-cooled "Gnome" that really put aeroplanes into the air. That was one of the triumphs of French engineering, and how appropriate it was, therefore, to have with them that night a great engineer like General Daum telling them about power plants of an imaginative type in the future. A full

circle had taken place and they must remember that up to the middle of the First World War they were wholly dependent on engines made by the French; what was, he thought, so satisfactory today to all those who loved France—and they all did—was their remarkable revival in design and production not only of aeroplanes, but of motor-cars as well. Their fighters and the "Caravelle" existed by reason of their producing again great and imaginative engineers.

It was the people who counted in the end, and among France's great engineers they had the great pleasure to welcome General Daum, of whom France might well be proud, and who had honoured them by his splendid pioneer lecture. He would ask them to show their appreciation in the usual way.

Following the lecture a dinner was given by the President and Council at 4 Hamilton Place at which the following were present:—

Monsieur Jacques Allez, President, L'Aero Club de France. Dr. A. M. Ballantyne, T.D., B.Sc., Ph.D., Hon.F.C.A.I., F.I.A.S., F.R.Ae.S., Secretary, Royal Aeronautical Society. Air Commodore F. R. Banks, C.B., O.B.E., M.I.Mech.E., Hon.F.I.A.S., F.R.Ae.S., Sales Director, Bristol Siddeley Engines; Louis Blériot Lecturer, 1948; Vice-President, Royal Aeronautical Society, Member of Council. Mr. A. D. Baxter, M.Eng., M.I.Mech.E., F.R.Ae.S., Chief Executive, Rockets and Nuclear Energy, de Havilland Engine Co. Ltd.; Member of Council. Madame Louis Blériot. Mr. E. C. Bowyer, C.B.E., Director and Chief Executive, Society of British Aircraft Constructors Ltd. Lord Brabazon of Tara, G.B.E., M.C., Hon.F.R.Ae.S., President, Royal Aero Club; Past President, Royal Aeronautical Society. Monsieur Jean Brocard, A.F.R.Ae.S., Director of Research, Louis Brequet Co.; Louis Blériot Lecturer, 1949. Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S., Past President and Honorary Treasurer, Royal Aeronautical Society; Member of Council.

Sir Sydney Camm, C.B.E., F.R.Ae.S., Director and Chief Designer, Hawker Aircraft Ltd.; Past President, Royal Aeronautical Society; Member of Council. Mr. J. R. Cownie, B.Sc.(Eng.), Grad.R.Ae.S., Chairman, Graduates' and Students' Section, Royal Aeronautical Society; Member of Council.

M. L'Ingenieur General Noël Daum, A.F.R.Ae.S., Technical Director, Nord Aviation; Louis Blériot Lecturer, 1959. Mr. N. J. A. Deaton, A.C.A., Accountant, Royal Aeronautical Society. M. Le Colonel J. C. de Loustal, Air Attaché to the French Embassy. Monsieur Henri Deplante, Technical Director, Générale Aéronautique Marcel Dassault. Monsieur Jacques Dupin, Technical Director, Nord Aviation.

Monsieur Claude Flamand, Chief of Special Team in charge of Design and Trials of Griffon Aircraft, Nord Aviation. Mr. L. G. Frise, B.Sc., A.F.I.A.S., F.R.Ae.S., Director of Special Projects, Blackburn and General Aircraft Ltd.; Member of Council.

General Pierre M. Gallois, Générale Aéronautique Marcel Dassault. Sir George Gardner, K.B.E., C.B., D.Sc., F.R.Ae.S., Director, Royal Aircraft Establishment; Member of Council. Mr. H. H. Gardner, B.Sc., F.R.Ae.S., Director and Chief Engineer (Military Aircraft), Vickers-Armstrongs (Aircraft) Ltd.; Member of Council. Mr. M. N. Golovine, M.B.E., A.F.R.Ae.S., Director, A.T.S. Limited.

Mr. R. Hafner, F.R.Ae.S., Chief Designer (Helicopter Division) Bristol Aeroplane Co. Ltd.; Louis Blériot Lecturer, 1954. Sir Arnold Hall, M.A., F.R.S., F.R.Ae.S., President, Royal Aeronautical Society; Director, Hawker Siddeley Group; Managing Director, Bristol Siddeley Engines; Member of Council.

Monsieur J. Jarry, F.R.Ae.S., President, L'Association Française des Ingenieurs et Techniciens de L'Aéronautique. Mr. E. T. Jones, C.B., O.B.E., M.Eng., F.R.Ae.S., Deputy Controller of Overseas Affairs, Ministry of Supply; Past President, Royal Aeronautical Society; Member of Council. Air Marshal Sir Owen Jones, K.B.E., C.B., A.F.C., B.A., D.I.C., M.I.Mech.E., F.R.Ae.S., President, Institution of Mechanical Engineers; Vice-President, Royal Aeronautical Society; Member of Council.

Mr. H. Knowler, A.M.I.C.E., F.R.Ae.S., Louis Blériot Lecturer, 1952.

Mr. P. G. Masefield, M.A., Hon.F.I.A.S., F.R.Ae.S., Managing Director, Bristol Aircraft Ltd.; President-Elect, Royal Aeronautical Society; Member of Council. Mr. M. B. Morgan, C.B., M.A., F.R.Ae.S., Deputy Director, Royal Aircraft Establishment; Member of Council. Dr. E. S. Moult, C.B.E., B.Sc.(Eng.), F.R.Ae.S., Director and Chief Engineer, de Havilland Engine Co. Ltd.; Vice-President, Royal Aeronautical Society; Member of Council.

Colonel R. L. Preston, C.B.E., A.F.R.Ae.S., Honorary Secretary, Royal Aero Club.

Mr. N. E. Rowe, C.B.E., B.Sc., F.C.G.I., F.I.A.S., F.R.Ae.S., Technical Director, Blackburn & General Aircraft Ltd.; Past President, Royal Aeronautical Society; Member of Council. Sir Harold Roxbee Cox, Ph.D., D.I.C., B.Sc., M.I.Mech.E., F.I.A.S., F.R.Ae.S., Past President, Royal Aeronautical Society.

Mr. S. Scott Hall, C.B., M.Sc., D.I.C., F.C.G.I., F.I.A.S., F.R.Ae.S., Scientific Adviser to the Air Ministry; Member of Council.

Sir Reginald Verdon-Smith, M.A., Chairman and Joint Managing Director, Bristol Aeroplane Co. Ltd.

The First Fairey Memorial Lecture

Sir Richard Fairey

by

G. W. HALL, F.R.Ae.S.

(Chairman and Managing Director, The Fairey Aviation Company)

Sir Richard Fairey. A posthumous portrait by Frank Eastman.

The First Fairey Memorial Lecture, "Sir Richard Fairey—An Appreciation" was given by Mr. G. W. Hall, F.R.Ae.S., on 5th March, 1959 at the Feltham Hotel, Feltham, Middlesex. This was the 34th Main Lecture of the Society to be given at a Branch and was held under the auspices of the London Airport Branch.

Mr. R. L. Lickley, F.R.Ae.S., Chairman of the London Airport Branch, opened the meeting by welcoming the President of the Society, Sir Arnold Hall, M.A., F.R.S., F.R.Ae.S. This was the first Main Lecture of the Society to be held at the London Airport Branch and they were delighted to have the President with them to preside at the Meeting.

Sir Arnold Hall said how glad he was to preside on such an important occasion and at the first of what they hoped would be a distinguished line of lectures in memory of Sir Richard Fairey, a celebrated member of the Society and President of the Society from 1930-34. Sir Richard had been an outstanding member of the Aeronautical Industry of Great Britain and of this particular part of the country and his interests in the district were being most ably carried on by their Lecturer. They were particularly glad to have Lady Fairey and members of the family present on this occasion.

Their Lecturer, Mr. G. W. Hall, was Chairman and Managing Director of the Fairey Aviation Co. Ltd., and had been with the Company almost all his working life, apart from a short period with Rolls-Royce Ltd. An interesting point was that while he was with Rolls-Royce, Mr. Hall had been concerned with the development of the engines used for the Schneider Trophy which had been a remarkable phase in British Aviation history. Then, more recently, Mr. Hall had led the team at Faireys which took the World's Air Speed Record for Great Britain with the Fairey Delta. It was a remarkable attainment. He had much pleasure in asking Mr. Hall to deliver the First Fairey Memorial Lecture.

Introduction

This first Sir Richard Fairey Memorial Lecture which I have the honour of presenting is also the first Main Lecture to be given at the London Airport Branch of the Royal Aeronautical Society—a branch that is young, but which, centred at Heathrow, awakens memories of Sir Richard and of the firm he founded.

I speak as President of the London Airport Branch of the Society, as Chairman of the Fairey Company, and as a relative of that great man, Sir Richard Fairey. The story I shall tell is my own as I know it and as I feel it. It is not only a story of the man, his interests and his influence, but it must also be a brief story of the Company he founded and of aeronautical achievements for which our country owes him so much.

This man, well over six feet in stature, of solid English stock, had a remarkable personality, combined with an enthusiasm and determination to succeed. He had a motto, a creed if you like, the theme of which has been the inspiration of many great men throughout history. "If the world does not please you, you can change it." This was not the boast of an arrogant man, nor the blaspheming cry of the irreligious egoist. This was the expression of his refusal to accept a world which would not progress. With this outlook he helped to change our way of life, but at the same time he respected and enjoyed the world around him.

Only two years after the founding of his own firm we find this quotation in the Company's Magazine, written by one of his own employees—"Our Managing Director is a man absolutely without side, and as straight as the proverbial gun barrel." He was a man who knew poverty as well as plenty. He knew the hard work and the sleeplessness of an apprenticeship combined with a spare time technical education. He began with the lazy softness of being the only son in a well-to-do Victorian family; he knew the spirit of a public school in Victorian days; and from this he was thrown into sudden poverty following on his father's death when he was only 11 years of age, and even at that early age he rose to the challenge, as the world he found himself in did not please him.

Charles Richard Fairey was a man deeply interested in all things and skilled in many—in aerodynamics and in backgammon; in sailing and in Patience; in shooting and in chess; in fishing and in astronomy. He was a friend of statesmen and ambassadors, of authors and poets, of sailors and fishermen, and of men who flew. He was himself mechanic, inventor, technician, businessman and ambassador.

If any excuse is needed that he should be remembered tonight then the trout streams and the covert, the sea and the air, will give it.

Early Life

Charles Richard Fairey was born at Ray House, in Finchley Lane, Hendon, on the 5th May 1887, very near the site which was to become the well-known Hendon Aerodrome. His father, Richard, was a pioneer, going to Canada with his twin brothers in connection with the timber trade, and we find many references to his management of the New Brunswick office of his firm. This Canadian background may well have sown the seeds of the younger Richard's interest in that vast territory. It was in 1892 that the elder Richard set up his own London firm of timber importing and exchange merchants, only to die some six years later. His mother, Frances Rebecca Jackson, was descended from the Shrive (originally "Sheriff") family, and this family can be traced back to Elizabethan times and the great sea battle against the Armada. We could dwell for a considerable time on the fascinating history of both these families and it is interesting to note that the poet Keats' family inter-married with the Shrives, and also that both family names were famous in carriage building in the coaching days. There is no doubt that this solid English stock, with its rich traditions, shaped the courage, the determination, and the personality of Dick Fairey, not to mention his enormous physical stature. He had three sisters—Frances Ethel, Anne Margery and Phyllis Annabel. His two surviving sisters, Mrs. Hulme and Mrs. Needell, both live not twenty miles from here and their scrap-books bear witness not unnaturally to their sisterly admiration. A younger brother, Frederick, died in 1901 at the age of four.

Dick Fairey had his first schooling at Hendon Preparatory School and his first school report, which we have found, is dated the 26th July 1893 when he was only six. Many biographers of men eminently successful in later life are only too pleased to draw attention to their very poor school reports, but certainly the early reports available show that Dick Fairey made steady progress and we are soon aware of his intelligence and of his independence. In order not to disappoint listeners tonight, we can say that the spelling and writing of his very early letters were not exactly good, but we find there is no wasted phrase and no undue sentiment. Here was a normal healthy boy staying with Grandpapa, with Aunts, or with schoolfriends, and quietly tinkering with wood, paper and string models, and reading all he could lay hands on. He writes to his Mother of the happy times he was having, of his friendship with his dog, of the hundred and one things in the garden, and says "has my gun come back, or my toy been found—give my love to Father" and these were signed "Your loving son."

Going through his library one sees side by side with books by his idols, H. G. Wells and Kipling, prize books from his preparatory school, and in one of them, dated 1895, is his name and address printed by himself with a little printing press that he possessed. It was this press which he used to help his father's many incursions into local politics, and he even wrote to local newspapers in support of his father, and to justify his unpaid services. The later letters to the more influential national Press make strange and interesting contrast.

Dick moved on to Merchant Taylors' School, then situated in London, with all the promise of a successful public school education and a business or professional career ahead of him. Then, in 1898, his father died. This was a grievous blow to the family and, as it turned out, of far reaching significance to him. There was far less to the estate than anyone had imagined and to continue for long at Merchant Taylors' was not just

unwise—it was impossible. When he was 13, the age for entering public school these days, he left, and for a few terms went to St. Saviour's, at Ardingly. His prize books here in 1901 and 1902 were for Arithmetic and Science—whether or not it was his own choice, the 1902 prize when he was 15, was Darwin's Journal. The books that passed through his hands, and are still in his library, make fascinating contrast, and he must have delighted in them from an early age.

He was always a skilled worker with his hands, having a delicate touch and infinite patience for perfection. At the close of his life he still maintained and was very proud of his workshop, where he was producing some exquisite things in cedar wood. It is not surprising, then, to find a little text-book, an early possession, entitled "Carpentry Workshop Practice," with the inscription "To my dear little Grandson, Charles Richard, from Wm. Jackson, Snr." (his maternal grandfather). How quaint the Victorian formality seems these days!

On leaving school, with what many would now regard as little enough schooling with which to challenge the world, there developed a determination to break away from the poverty of their existence as a family. He boldly took the lead, feeling it his duty to act as "father" and look after the family. He realised his lack of knowledge and was impatient to gain a practical training in order that he might play a full part in the great technical revolution that was taking place around him. We are always seeing the repetition of events, and here was something taking place that was analogous to the modern Atomic age—he was determined to take a share in the great advances in technical training that were becoming available, and having done so, later on in life we quite naturally find him a patron of modern methods and institutions to give such training.

The Jandus Electric Company in Holloway offered Dick Fairey a job at the princely sum of 5/- a week and this, moreover, through the good offices of a friend. He was given the privileges of a premium pupil without having to pay a premium, and this generosity on the part of the Managing Director was another of those quite small but important things that helped him along the way, and for which he never failed to be grateful. This firm was small, but it gave him the sound practical training he needed and he certainly could not have afforded any other course. Jandus were manufacturing electric lights—arc lights—to illuminate London's streets and shops, and we find it hard now to imagine the rows of arc lights which were the wonders of the age in street lighting.

He did not bemoan the twist of fate that so ordered his course of training. He considered that he was lucky to be able to go to College at the same time as working in a factory. The City and Guilds (Finsbury Technical College) was four miles from the Works and for the price of a cable tramfare and a few shillings a term on tuition, he studied four subjects a term, for five nights a week, under the great teachers of Electrical Engineering. Professor Sylvanus Thompson was his guide and friend, and Castell Evans and Darling also took a personal interest in him as a pupil.

His road to final qualification was long but straight. He passed his examinations and at the same time went through the departments of the firm until he was able to take charge of installing electric light in the docks and warehouses at Heysham Harbour. But, as he readily admitted himself, a swollen head and his strong independence for individual action cost him the sack. However, with the experience behind him he soon got another job, this time as an analytical chemist on boiler feed water and fuel analysis with the Finchley Council at their power station. A man's wage at last meant that Dick was now self-supporting, and he added to his income by lecturing in the evening on engineering subjects at Finchley Technical College and at Tottenham Technical College.

He had many friends whom he never forgot in later life. They loved boyish adventure and there is the story of the time they took Dick's sister with them to photograph an Egyptian mummy. They even insisted that Margery was with them when they developed the film in the darkroom, but none of the evil commonly attributed to association with the relic appeared to be communicated to them. No doubt they were all very disappointed! The same spirit of adventure, coupled with a sense of opportunity, was satisfied when he managed to be ahead of his boss at the power station in the mornings by the simple expedient of sprinting down the garden and over the railway as a short cut to the power station when the boss was sighted passing the house on his way by the more orthodox route.

At this time Dick was over 6 feet 5 inches in height, which earned him the nickname of "Tiny" and many of his rivals declared this had contributed to the range of his early flying model aircraft. He certainly formed an admirable launching platform.

It was in 1901, before he started his apprenticeship, that his mother was married again, and as far as I was concerned, Fate intervened to ordain that I should become the "kid brother" of the family, and grow up in the environment of the early struggles and be acquainted with so much of the story I am now telling.

The Formative Years

There is never a period of history that does not cover some change, some revolution in our way of life, but not for many years can we look back on this and appreciate, or sometimes regret, the full implication of it all. Everyone can grasp an immediate and obvious opportunity but not all can foresee, as he did, the importance of the changes taking place and fully appreciate their outcome. Great men are often considered lucky to have been born in their particular age, and Dick Fairey was always ready in later life to congratulate himself on having been born in a progressive age and having been forced to learn the hard way. But he would have been as successful a buccaneer as he would have been a farmer. He could have built the railroads of the continents as well as the atomic reactors, or the Martian space ships of a future age. He was born that way and he made himself that way. The world was changing and he would change what in that world did not please him, or rather what in that world had not, in his

estimation, yet been developed for our fullest advantage.

The railways of this country were still developing and the canals were to be strangled. The "Flying Scot" had already been leaving London on its smoky and noisy race to Scotland for twenty-five years before Dick Fairey was born. The motive power was there and the factories had come to stay. The pneumatic tyre was arriving and he had owned an amazing bicycle by the time he was eight. Those journeys to College were enlivened by the rumbling and clattering of the first tramcars and buses. The electric dynamo, with its porcelain and copper, was opening up new fields and horizons, and boyhood was fascinating, and such fun for one quick to understand and learn, and above all to think. What stimulating thought there was. Darwin, Huxley and Spencer were ploughing through the philosophy of centuries. Young Dick heard his own voice on the wax cylinder of the phonograph; he talked into a primitive telephone; and the motor car was coming as a method of transport. Conquest of the air was still being ridiculed.

Many years later Sir Richard spoke of the pride in the pioneering achievements of those days when the world believed that the material stumbling blocks were about to be removed, and we cannot do better than quote his own words. "It seemed that these achievements must go on and on for ever, to the general good, and we were on the threshold of a new world from which the curse of Adam had been lifted. The fear of the machine had not then been born."

Some forty years before Dick Fairey was born, Stringfellow had flown his first model, and two years before his birth there had been held the Second Aeronautical Exhibition at Alexandra Palace. The end of 1903 was the turning point in aeronautical history when the Wright Brothers achieved manned controlled flight. This was the background to his early interest in flying machines. Books, papers, conversations, all were greedily absorbed. Jules Verne and H. G. Wells fed his imagination and it was H. G. Wells who became interested in the young man playing with aircraft models and talked to Dick at length over the garden gate as to what their future might be. In the study today are the complete works of H. G. Wells, including an autographed set of the limited Atlantic Edition.

The first models were made while he was still at school and were of cane and brown paper, but as he had more time and a little more money to spare, so the models became more sophisticated and successful and the materials far different. Some models had floats, some skids, and the parks and the ponds were his favourite haunts. Other and now famous people were his friends and acquaintances with the common interest, and among them was Alliott Verdon-Roe who won a model competition at the Alexandra Palace in 1906. Dick's own flying models were beautifully constructed and he used to raid the house for silk with which to cover the surfaces: his sisters well remember his demands upon them and the pervading smell of home-made dope. The motive power was elastic and we still have a record of the correspondence he had with the manufacturers because those first sub-contractors of his

FIGURE 1. Dick Fairey with his 1910 prize-winning model.

were not being consistent in the quality of their product. His inventiveness was to the fore when he modified an early type of egg beater and then a hand-drill to wind up the elastic motor.

In 1910 he entered the Model Aeroplane Competition at the Crystal Palace with his model, and swept the board by winning outright the Challenge Cup. He also received gold medals as first prizes for steering, long distance and stability. A silver cup was also awarded to him for the best model. This was a twin-engined aeroplane of the Canard type with the tail plane leading and with two-handed pusher propellers. The braced structure is interesting and he had already experienced and obviated troubles with regard to torque reaction. This latter point is interesting when we see later in life the development of his own P.24 engine which was a forerunner of the present engine development in the Company's successful Gannet. In building his model Dick had inadvertently infringed some of the patents held by J. W. Dunne, by using varying incidence throughout the plan form, and a meeting followed that was later to result in a partnership. When this model was commercialised it was under Licence from Dunne.

Also at this time he was interested in a full-scale aeroplane and was engaged in helping—in his spare time and for sheer enjoyment alone—a Mr. Everett who was building a monoplane in that same field that was to become Hendon Aerodrome.

The success of his model at the Crystal Palace represented wealth and the key to a new career. An interview was arranged with the Manager of the London store of A. W. Gamage who already had a flourishing kite and model aeroplane department.

The story of that first commercial transaction is typical of the man and yet even he must have been

agreeably surprised at the result. With his model carefully packed in its case, he arrived on the fateful morning, confident of his product, but nervous of the treatment he might receive from such a successful business man. From Finchley he had taken one of the new-fangled taximeter cabs (an event in itself!) and this was left outside the store to tick away a fortune, in a gamble for a larger fortune. "Could Mr. Fairey demonstrate his machine, and would it really fly?" Mr. Fairey explained that he had a cab outside and was prepared to take him to Hyde Park immediately and to demonstrate the model. The mortgage on the taximeter cab was then mercifully taken over by the firm of A. W. Gamage. The first embarrassment was over. "Could the machine be guaranteed to fly a hundred yards?" A following "trade wind" and a careful launch and the first demonstration was successfully finished. Confidence mounted and terms were discussed. Again the gamble of the shrewd man who knew now that he was selling a winner. That machine was far in advance of any other on sale at that time and Fairey put its value high to Gamages. A second flight with a range beyond the first mark, and the story suggests that running beside Fairey to retrieve the model was an excited manager who was saying "One more flight like that, young man, and the money is yours." Realising that the chances were against a third flight of such magnitude Fairey stumbled over the model as he retrieved it, with consequent damage. There was genuine pity on the part of the Manager but—the successful punter knows when to stop. Both men were gambling and neither lost. Fairey got his price and the store its profit. The little booklet

The
Fairey High Flying
Model Aeroplane.
Licensed under J. W. Dunne's Patents.
Winner of the Challenge Cup.
1st Prize, Gold Medal for Steering.
1st Prize, Gold Medal Long Distance and Stability.
The Kite and Model Aeronautic Association June 4th, 1910.
Silver Cup for best Model, The Aero Models Association, August, 13th 1910.

FIGURE 2. The cover of the leaflet for the 1910 model.

of instructions bears witness today to the thoroughness with which Fairey kept his side of the bargain.

The money earned by down payment and licence fees was the material reward for years of hard work, but it would have to be put to good use. It must not be squandered. Fairey sat back and thought. Here was an opportunity to go forward. He had demonstrated his ability, and now had capital behind him. Offset against this, he was by now well established at the Finchley Power Station, and had a secure job for life there with every hope of eventually becoming Manager. But he had the urgent desire to start a new career in flying. On his thoughts becoming known there was a Sunday of gloom. All the elders of the family descended on the house and spent considerable time in trying to convince the young man how crazy he was in throwing away a good job and entering into a hazardous interest which had no future. Dick, however, was determined and unconvinced by their pleadings, and the following morning he gave notice to the Finchley Power Station, and then joined Dunne at Eastchurch, in the Isle of Sheppey. The desolate "Isle of Sheep" was the "cradle of British Aviation" and here was another gateway through which Dick Fairey strode, erect not stooping, sure of his future and of his name in history.

Eastchurch to Fairey Aviation Company

The flying ground at Eastchurch was the property of Sir Francis McClean, and here were gathered the body of enthusiasts who built and flew gliders and aeroplanes. John William Dunne had commenced his flying experiments in 1900 and later formed the Blair Atholl Syndicate to develop his tail-less aeroplane. His first aeroplane had been designed and built at Blair Atholl in 1908 after which the Syndicate had decided to move its activities to Eastchurch. Here also the Short brothers were busily engaged.

Here was the chance to see, to learn, and above all, to fly. Aviators taught themselves to fly in those days and Dick was no exception. Many were the stories of his days there and of their early attempts to fly. One day, tired of watching a little man experiment with an aeroplane he could not fly, Fairey and his friend decided to try themselves. They managed to just lift it off the ground, but crashed it almost immediately, damaging the propellers. They repaired it, but were a little scared lest the repair should prove unsafe. However, they consoled themselves with the very practical thought that it was unlikely ever to fly, and in any case the owner himself could not fly it!

It was in this atmosphere of courageous experiment that Dick and his friends learned hard lessons—it was here that they flew aircraft with fantastically low wing loadings and with power weight ratios absurdly low by our modern standards. It was here that he always said he knew perfect bliss and it was here he met a party of Cambridge undergraduates, three of whom—Vincent Nicholl, "Wuffy" Dawson and Maurice Wright—were to join him later and to form a long business association.

He joined Dunne as Chief Engineer and supervised the building of his aeroplanes, one of which flew the Channel in 1913. On the Dunne biplane he went to

endless pains to fathom out and accurately stress the aircraft and by so doing removed redundant weight. Stressing in the early days was very much by rule of thumb methods and here was a positive technical approach to the problem and we see the same approach later in life when he dealt with the stressing of yacht masts. These early craft designed by Dunne suffered from excessive stability and a consequent lack of control.

At Eastchurch he met the Short brothers, and it was Horace Short who, appreciating Fairey's ambitious ideas, persuaded him to join them in 1913, where he was later to become their Chief Engineer. Dick Fairey regarded Horace Short, the man with the huge brain and the almost limitless ideas, as the greatest engineer he had ever met. In later life he described him as a genius and claimed to have learned more from him than from any other man. Horace Short was the finest type of practical engineer, and his machines had a reputation for safety as well as performance. It was Shorts who built the first British machine to fly a closed circuit mile, piloted by Moore-Brabazon (now Lord Brabazon). Just as Fairey influenced the design of later aircraft, so had Short influenced the maturing of aeronautical engineering and the knowledge gained from his work under Horace Short must stand as another great turning point in our story.

In the early days at Eastchurch the art of flying was young and there were many accidents, with loss of life; the reaction to this by Dick and his many friends was one of making the most of life with the maximum of enjoyment. They raced around the countryside together on the early motor-bicycles and cars, and local towns heard them coming and trembled at their approach. Dick was particularly in the company of Nicholl, Dawson and Wright at this time. A young City solicitor, the respectable Charles Crisp, is reputed to have pulled them out of many a scrape.

At the outbreak of War and with the newly-formed Royal Naval Air Service, these friends of Dick's joined up and he went with them, only to be pulled out and told that there were plenty of heroes but few aeronautical engineers. He was sad and disappointed at being parted from their activities and he also wanted to fly, so he again attempted to join up, this time in the Royal Flying Corps. This resulted in more trouble and he was clearly told where he stood in that his job was to design and build aircraft.

It was also in that year that he had to leave Eastchurch to go to the new Short Brothers factory at Rochester, which made him more restless than ever as he was away from Eastchurch and its flying associations. Then an opportunity occurred. Through a mistake he received his calling-up papers and he used this to advantage and this led to further trouble. Not only did retribution fall upon the hapless heads of those who had issued the calling-up papers, but he was sent for by the Admiralty, once again to be put in his place.

His efforts to join the Services and the trouble he had caused had brought him very much to the direct attention of the Admiralty. It was as an outcome of a meeting, I believe with Admiral Sueter, that he left Short Brothers in 1915 to form his own Company. Thus the Fairey Aviation Company was born. Backed by the goodwill of the Admiralty, with a sub-contract order for aircraft, but no factory, he was on his own feet and harder work than ever before was going to be necessary for success. But he was independent and determined to go forward. The life of the man was about to be submerged into the life of a Company, of its people, its products, and its record of achievement.

The Fairey Aviation Company

The Fairey Aviation Company was registered in 1915, and started its life initially in a small office in Piccadilly. From this it was necessary to find a suitable factory so search was made to the west of London where a factory was found at Hayes: here an arrangement made it possible to rent floor space to carry out his contract. Also a field was chosen on the other side of the railway, for use as an aerodrome, and this is now the site of the Fairey Aviation Company at Hayes.

His aircraft work rapidly expanded and very soon practically the whole factory was taken over for this purpose. It was at this stage that an attempt was made by the owners of the

FIGURE 3. Dick Fairey with the Dunne tail-less biplane.

FIGURE 5 (*right*). The Fairey Campania with Rolls-Royce Eagle engine.

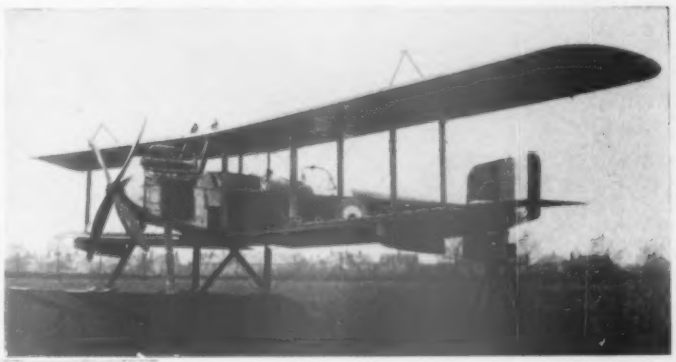
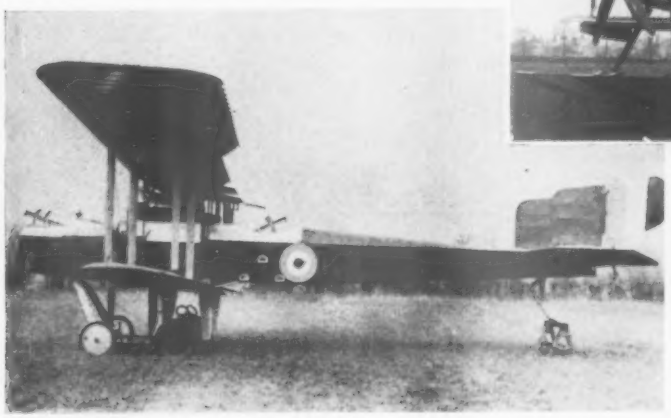


FIGURE 4. The Fairey F.2 of 1916 with two Rolls-Royce Falcon engines.



property to encroach and run his business. This led to drastic action on Fairey's part. One day, taking matters into his own hands, he walked straight into the managing director's office, sat in his chair, and sending for the senior executives he told them he was in charge. As we can well imagine this led to major conflict but he maintained his position and won the day.

He realised, however, that he must have his own factory. Therefore he built offices and hangar accommodation on his aerodrome site and later this became the headquarters of the Company. Additional to this he acquired his own seaplane base at Hamble.

From the formation of the Company in 1915 to the end of the War in 1918 great strides were made. The Company's first aircraft, the F.2, a twin-engined fighter with folding wings, was designed and built in 1916; this was followed by the Campania, the Hamble Baby, the N.9. and N.10., and the Fairey Series III.A., B. and C. Already in three years Fairey had produced some very successful aircraft which were giving a good account of themselves.

During the period 1918 to 1924, the Fairey Series III.C. and III.D. became famous in their world-wide application and activities. Besides being in full operational use by the Services they entered other spheres. A modified III.C. was in the 1919 Schneider Trophy Race, piloted by Colonel Vincent Nicholl, who with "Wuffy" Dawson, Maurice Wright and Charles Crisp were now with the Company. Also in 1919 a III.C. was used for flying the *Evening News* from Isleworth, on the Thames, to Margate, piloted by Sidney Pickles, and it was in this aircraft that Sidney Pickles hit the headlines in March 1919, by flying under the Tower Bridge. I believe, and am almost certain, that Fairey was a passenger on this occasion.

The Portuguese Government purchased III.D. seaplanes and a special version of this type in 1922 was flown by Commander Sacadura Cabral, of the Portuguese Navy, across the South Atlantic from Lisbon to St. Paul's Rocks, via the Azores (2,555 miles in 29 hours). I believe I am right in saying that this was the first flight across the South Atlantic.

A number of III.D. seaplanes were also purchased by the Royal Australian Navy and one was flown completely round the coast of Australia by Wing Commander Goble, covering 8,568 miles in 90 hours.

In addition, four III.D. aircraft flew from Cairo to the Cape, and in 1924 ambulance versions were being supplied to British Guiana, and a seaplane of this type with clipped wings was entered for the King's Cup Race.

From this background of success we see the Pintail and in 1923 came the famous Flycatcher, a Naval single-seater fighter which, in its many rôles as carrier-borne or seaplane, became so popular and gave such good service, and then in turn the large four-engined flying boats, the Atlanta and Titania, and after that the Fremantle and the Fawn.

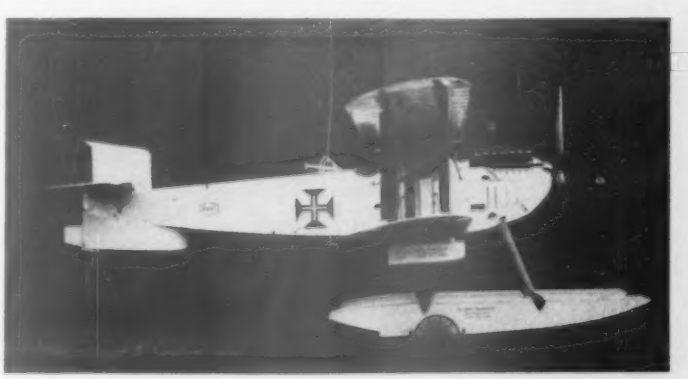


FIGURE 6. The Fairey III.D with Portuguese markings.

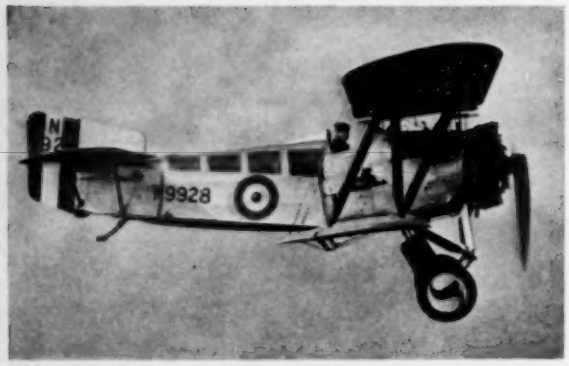


FIGURE 7. The Fairey Flycatcher.

The Fawn became a turning point in the history of the Company, in that Fairey was very unhappy with this general purpose aircraft as he felt it was being asked to do too much, in having too many varied duties, and in consequence would not be a satisfactory Service aeroplane. It was while he had these worries on his mind that he saw the 1923 Schneider Trophy Race at Cowes and was very impressed and stimulated by the Curtiss D.12 racers.

Directly after the Race we find him working long hours on his own drawing board at home (and playing endless games of Patience) and the outcome was an approach to the Government to support him in his new ideas for a two-seater bomber which he claimed would be faster than any existing single-seater fighter. His proposals were rejected—but Fairey had seen a new vision ahead and had no intention of being diverted from his objective. He, therefore, raised all the money he could, virtually mortgaging the Company in the process, and sailed to America. He came back with the rights of the Curtiss D.12 engine, the Reed propeller, wing surface radiators, and many other design features. In the highest secrecy, on a private venture basis, he set to work with his team to produce a new aircraft. The outcome was the Fairey Fox in 1925, a remarkable aeroplane for its time. He more than vindicated his claims with regard to its performance and set a new pattern before the world with regard to performance and streamlining of military aircraft.

He upset a lot of people in the process and the reward for his success and achievement was an order for only 18 aircraft. But, based on the Fox, a new specification was drawn up by the Air Ministry which went out to tender, the successful design being the Hawker Hart with the Rolls-Royce F.10 engine. Naturally Fairey was very disappointed that his pioneering efforts had not been fully rewarded. He had the sole consolation of having started a new trend of development in this country.

Not to be defeated, however, he set about selling his aircraft abroad and to further this the present Avions Fairey Company was started in Belgium. His efforts in this direction were rewarded by success and he sold many aircraft derived from the original Fox, the Belgian

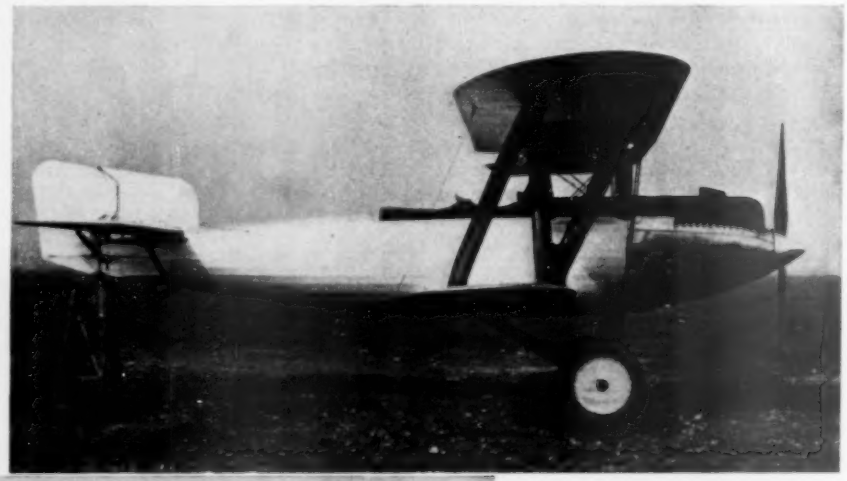


FIGURE 8. The prototype Fairey Fox.

FIGURE 9. The Fairey III.F.

FIGURE 10. The Fairey Long Range monoplane.

Air Force being based on this. His export orders were at that time the largest ever received by a British aircraft company.

The III.D. was re-examined in light of the new knowledge and the outcome was the famous III.F., both landplane and seaplane. Whereas the III.D. was a wooden aircraft the III.F. was a metal one and long was its reputation in many parts of the world and in different forms.

The equipping of No. 12 Squadron, Royal Air Force, with the Fox had an interesting sequel. This Squadron was particularly proud of its new bomber aircraft which were considerably faster than the latest fighters then in Service and the new Squadron emblem included a fox's head with the inscribed motto "Leads the field." Fairey felt honoured by this and saw in it an idea for a Company badge. He requested his sister, Mrs. Needell, to produce a design and the result was the now famous Fairey badge with the winged ears and the inverted triangular head. A similar motif was used for his personal bookplate.

In 1928 we see the Long Range Monoplane, a beautifully streamlined aircraft for its day, and this type of aircraft in 1933 took the World's Long Distance Non-Stop Record of 5,309 miles.

1930 produced the prototype of the Hendon bomber, unique as being the first large cantilever monoplane bomber.

In 1933 came the T.S.R. Mark I the prototype of which crashed; undaunted Fairey continued work on this as a private venture. The aircraft was rebuilt in a remarkably short time and the type was later to become the famous Swordfish which gave such wonderful service from the outset until the end of the last War.

New developments of the monoplane started in 1936 with the Battle, followed by the P.4/34, which later became the Fulmar. Engine development was started: the famous P.24 which flew successfully was a forerunner of the present Double Mamba installed in the Gannet. Also a large four-engined civil air liner project, the F.C.1. was started, but was unfortunately stopped at the outbreak of the War.

During the years between the First and Second Wars, Fairey had steered his Company safely through many stormy passages and had survived the period of intense depression in the aircraft industry. From his small beginnings he had built up his Company which was able to play a big part in the vast production of aircraft required during the Second World War.

Fairey had always appreciated the necessity of a good aerodrome with his factory and after the building of the present factory on his original aerodrome site, Northolt was used. This was a Royal Air Force aerodrome and the Company was limited in hangar space. He thought this over and the outcome was the acquisition of a freehold site at Heathrow which would meet his long-term needs and this became one of the finest aerodromes in the country and is now part of the present London Airport. His intention was to build up here for the future rather than at Hayes, so that he would eventually achieve a good factory alongside an aerodrome. Shortly before the outbreak of War he was prohibited from building at Heathrow and with the necessity for expansion and to meet Government requirements with regard to Dispersal, the Stockport factory was acquired.

It was a sad day for Fairey when, towards the end of the War, his Great West Aerodrome at Heathrow was requisitioned and the Company was compelled firstly to use Heston, and then White Waltham.

After the War, having seen demonstrations of the early helicopters, Fairey at once recognised their future

FIGURE 11. The Fairey Swordfish.

FIGURE 13. The Fairey Rotodyne.

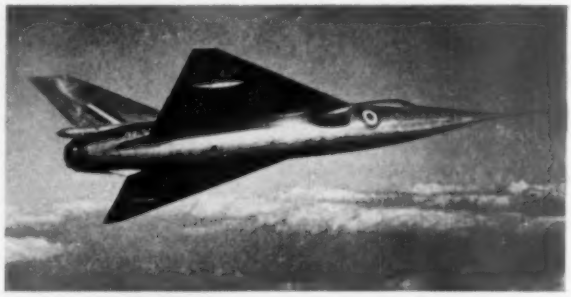


FIGURE 12. The Fairey Delta 2.

which he discussed with his colleagues. He pointed out clearly their limitations and said that helicopters would be of little value unless, besides useful load, they also had speed. As a private venture the Company entered this field and with the Gyrodyne obtained in 1948 the International Speed Record for Helicopters at 124·3 m.p.h. Continuous research and development on rotary wing aircraft have taken place since then and at the present time, as the outcome, we have the Rotodyne.

Pioneering was always encouraged by Fairey and as a result of research work undertaken for the Ministry of Supply, developments led to new outlets for the Company finally in the form of guided weapons and research aircraft. On the 10th March 1956, the Fairey Delta 2 obtained the World's Speed Record at 1,132 m.p.h. Fairey was delighted on receiving the telegram with regard to this achievement and was proud of the long continuity of pioneering which had enabled the Company to produce the first aircraft officially to achieve over 1,000 m.p.h. It is sad that he did not live to see the recent record of the Rotodyne in achieving 190 m.p.h. round a closed circuit course, in fulfilment of his contention that a vertical lift aircraft to be successful must have speed.

He instigated many activities in other fields, the outcome of which basically forms the interests of the present Company.

The Royal Aeronautical Society

After this chronicle of the Company it would, I think, be interesting to all of you here to link the man and his work with the Royal Aeronautical Society.

Following his election as President of the Society of British Aircraft Constructors in 1922, he was elected the following year to the Council of the Royal Aeronautical Society and he was mainly responsible for the Society of British Aircraft Constructors' grant to the Society. He personally contributed to the funds on many occasions and was, in fact, known as the "Fairey Godfather" of the Society.

To encourage membership of the Society in 1927 he instituted a system of paying for the examination fees, entrance and first year's subscription fees for his employees, and this lead was soon followed by others.

In 1930 he became President of the Society, a position he held for four years. During his Presidency, Lord Amulree suggested that a medal be struck to be awarded for important achievements leading to advancement in Aeronautics, and Fairey undertook the cost of the British Gold and Silver Medals. In 1936 he was awarded the Wakefield Gold Medal for his original work on the variable camber wing of some twenty years before. On the 5th April 1935, he gave the free use of the Company's Great West Aerodrome at Heathrow for the Society's Garden Party, and in 1937 he donated a considerable sum to the Endowment Fund. The Society throughout this period had good reason to be grateful for his unbounded generosity.

In 1930 he gave his Presidential Lecture on the Growth of Aviation, in 1950 the Wilbur Wright Memorial Lecture, and on many occasion lectured at various branches of the Society.

In 1950 he was awarded the highest honour of the Society by being made an Honorary Fellow.

Yachting Activities

It was in 1927 that long hours and hard work were beginning to tell. Having risked all on the Fox he had only received a small reward from his own country and it had been necessary to re-stabilise his Company financially after spending so much pioneering money on this venture. He had, however, achieved this by exploiting sales abroad and in the success of the III.F. and with production work flowing, it was possible for him to sit back and reflect.

He was advised to have more relaxation, and although he had previously taken up golf in a whole hearted and strenuous manner, as portrayed by the Cups he had won, it was insufficient to meet his needs. So, with the true Englishman's love of the sea, he began to take a serious interest in yachting and bought the slow 12 metre yacht "Modesty". As might have been expected, he became determined to master the art and to study the reasons for "Modesty's" record of racing failure. In his mind what better start could he have than the slowest boat in the fleet.

He found there was no satisfactory design record of the rigging and mast. Rule of thumb methods predominated, so he set to work and applied his knowledge of stressing and brought in competent technicians to help him. He had a small wind tunnel built to study air flow and sail setting under various conditions of wind and boat positions encountered during a race, and much valuable information was obtained from this. The

outcome, when put into effect, was a considerably improved performance, with major saving of redundant weight.

He also found the hull was far from right and this had to be re-shaped. Gradually his experience as a helmsman, combined with the speed and manoeuvrability of the boat, increased and, as with aircraft, he was gaining valuable experience. He put his whole heart and soul into achieving success.

In 1929 he commissioned Charles Nicholson to build for him to his requirements a new 12 metre yacht, which was named "Flica". She was fast and Fairey was by this time a magnificent and determined helmsman. In 1931, 1932 and 1933 she was easily top of the 12 metre Class and one year, after the old custom of flying the winning flags had been happily revived, she sailed the last day of the season with 36 flags—24 firsts, 10 seconds and two thirds. "Flica" was a beautiful sight under the blue and cloudless sky with the sun glittering on the water. In 1932 she won 50 firsts in 58 starts—a champion in her Class.

A limit to achievement had been reached in the 12 metre Class so Fairey purchased the famous "J" Class racing yacht, "Shamrock V" and started again in this large Class. He found, however, that the regimented sailing with a professional crew of 22 was not so much fun as the smaller Class and as experience grew with the boat he realised its long-term limitations with regard to development. It was after "Endeavour's" challenge for the America's Cup that he sat back and reflected again. Here was the need for a new approach. A fast and manoeuvrable boat was required, capable of sailing the Atlantic, and one that could be developed to meet the Americans on equal terms.

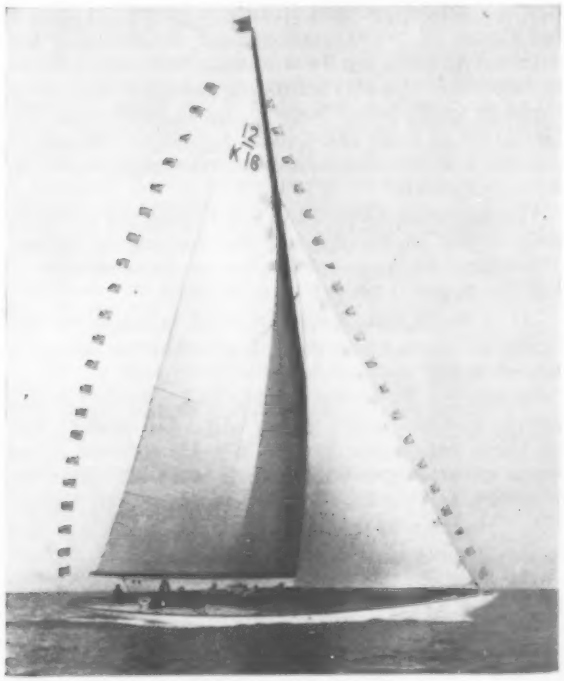


FIGURE 14. The yacht "Flica."

He conceived the idea of a new Class, known as the "K" Class, and in 1935, as Commodore of the Royal London Yacht Club he challenged the Americans. It was now more than apparent that the acquisition of his 581 ton motor yacht "Evadne" was for the long-term purpose of acting as a "mother ship". The challenge was not accepted so having sold "Flica," he purchased a new 12 metre yacht, known as "Evaine," which again achieved excellent results in her Class.

As a matter of interest, "Evadne" became H.M.S. *Evadne* during the War and successfully depth-charged a U. boat on North Atlantic patrol in 1944.

Throughout this period up to the outbreak of War, at no time did he fail to keep in close touch with the activities in the aircraft field, and maintained constant and ruthless pressure on the Company, as many of us can well recall.

British Air Commission

Shortly before the War, having seen activities in Germany which in his mind constituted large scale production of military aircraft, Fairey was very concerned from a national aspect. His attempts to establish this were unsuccessful and when he was finally told that he was only searching for work for his own Company, he went back to yachting.

With the outbreak of the War, and on the appointment of Lord Beaverbrook as Minister of Aircraft Production, Fairey was at once called in and readily undertook intensive work with regard to the planning of the Aircraft Industry for production.

The position with regard to military aircraft in this country at the start of the Second World War is well-known. Not only did the country have to step up its own production but it had also to obtain aircraft from elsewhere. America was the obvious answer. Sir Henry Self, who had been a Deputy Under-Secretary of State for Air, had headed Missions to the United States. In the spring of 1940 Sir Henry Self became Director-General of the Air Section of the British Purchasing Commission, known as the British Air Commission.

Lord Beaverbrook felt that Fairey would render valuable service with the British Air Commission and in his introduction to Sir Henry Self he said "Fairey is a fine man. He has been in the Aircraft Industry here for a lifetime. He is derived from New Brunswick on the Miramichi. He has a good character, excellent reputation, splendid presence, charming manner, an agreeable personality". This reference to New Brunswick by Lord Beaverbrook is a delightful touch, and who could wish for a better testimonial.

So on the 6th August 1940, Fairey arrived in New York, having flown the Atlantic from east to west on the first Atlantic flight of the Sunderland flying boat "Clare." By November 1940, the Commission was well established in Washington and Fairey was Deputy-Director-General I and Controller of Production. Later, when Sir Henry Self was appointed to other special duties, Fairey became Director-General of the British Air Commission

in 1942. It was also in the same year that he received his knighthood.

Not only had he to be a persuasive diplomat, but he also had to strike a shrewd bargain. Money, particularly borrowed money, could not be wasted. There was also the almost insoluble problem of standardisation and he had to ensure the satisfactory development and delivery of aircraft, and armament, to meet the requirements called for to enable the maximum benefit to be obtained by the fighting services.

During his visits to American factories and Research Establishments he made valued and lifelong friends, not only for himself but for this country. There were speeches to be made to eminent gatherings and interviews given to the Press which made front page news. Reading through these speeches and looking at the faded cuttings there is no doubt that he spoke his mind as a complete patriot whose most earnest desire was to cement Anglo-American friendship and to present the true picture of Britain to his American friends. We know that he also poured out his heart to this country, not in anger, but in anguish, at the propaganda that was giving America such false impressions.

The Americans loved him and he was held in the highest respect. On the 24th January 1944, at the Waldorf-Astoria in New York, his friend Ted Wright, then with the War Production Board, but acting as President of the Institute of the Aeronautical Sciences, presented him with an Honorary Fellowship of that Institute. I might quote part of Fairey's reply—"only they (the engineers) know by what hard degrees the conquest of the air has been achieved," and then later, as if thinking rather wistfully of the early days, "the younger generation of engineers now in training are fortunate indeed to have access to such a lavish fount of knowledge, a marked contrast to the lot of their forefathers in aviation."

The intensive hard work and the worry and responsibility were taking their toll, and with his health failing he was forced to resign his post on the 30th April 1945. There followed three anxious months at the Massachusetts General Hospital in Boston, under the careful treatment of Dr. Paul Dudley White and the skilled surgery of Dr. Reginald Smithwick.

In 1947 the United States Government awarded him the Medal of Freedom with Silver Palm for "exceptionally meritorious service in the field of scientific research and development." This award was made at Kindley Field in Bermuda where, in accordance with Doctor's advice, he spent the winter months of each year.

On his return to this country after his major operation he adopted the attitude that he would rather live four years of a full life than be an invalid for ten years. In consequence he led a strenuous life that many a younger man had difficulty in following.

The Squire of Bossington

At his home at Bossington, in Hampshire, with its wonderful fishing and the natural life of the Test Valley, he settled down to look after the welfare of his estate, at the same time frequently visiting the Company and maintaining daily contact by direct telephone.

He came naturally to Bossington with the hand and the eye of the sportsman and the patience and skill of the fisherman, and here again we find that strong application of purpose to master what was before him. He had seen other homes—he had lived in them—but he felt that this was made for him and he was meant to be there. Salmon, trout, grayling, wild fowl, pheasants, partridge—all were to be found in this perfect English countryside.

Now further major projects challenged him, not only in dealing with the farms but the chalk streams and woodlands that were overgrown and needed attention following years of neglect during the War. He set to work with all his old energy and enthusiasm. Ponds were dug and river beds cleaned out. A trout hatchery was developed, the temperature being controlled by warm spring water. From practically nothing the fishery was built into one of the finest in England and by 1952 trout of over four pounds in weight were being caught—by 1953 some were nearer six pounds. Even more remarkable was the fact that in some instances the rod, reel and line he used weighed less than half a pound. His methods were unique and his understanding of water life and the science of fishing was quite remarkable. He designed and tied his own flies and one—Father's Irresistible—was duly recorded.

He had used a gun from his childhood and from the early expeditions on Sheppey and the cold raw morning shoots on the Fens, he came again naturally into this sphere.

He fought against those who were proposing to ruin the lovely Test Valley—those who were proposing to lower the water-table by dredging the streams in order to grow wheat. He felt that wheat should be imported from Canada rather than attempt to produce it from a small area of water-meadows, and he felt that the natural life, including the wild duck and snipe, should be preserved. He also fought the indiscriminate use of chemical sprays which were killing so much wild life. He did not so much object to their use but to the lack of control, and felt that scientific knowledge was being wrongly applied.

He improved the land and had a measured approach with regard to maintaining the balance of nature. Throughout his sport and his pleasure he never allowed ruthless slaughter for the sake of killing.

Here was a man deeply absorbed in the worth and beauty of nature and respecting and enjoying the world around him.

It was this life he had to leave to journey to London for an operation which was to be his last gamble, and he knew that he was staking all. He survived a few hours after the operation, then he heard the call of his forebears, and the English soil he loved so well claimed him. He lies near the little village church on his estate at Bossington.

A Great Man

I have attempted in a short space of time to give you an insight into the life and work of the late Sir Richard Fairey, but much remains to be told. I feel humble in

my presentation but trust that I have given you sufficient to justify the payment of a deep respect to that great man and his achievements.

In my opinion Sir Richard was a great man, one of the great men of the century. The true facts of his achievements should be sufficient witness of this. He had his faults. He could be hard in business, but he was a business man. He could be quick tempered but with reason. He made the issue so clear one knew where one stood. He hoarded many of the material things as well as the memories, but why should he not be sentimental? He had difficult traits, but many were lovable. Nobody dare speak as he played his game of Patience, not because he might fail—he seldom did—but because his mind was full of other things—the game was just a cloak to cover the workings of his mind on other more weighty issues. He was never at a loss on any subject a second time—he always studied it to perfection for the next occasion and could amaze the experts with his knowledge. His memory was unfailing: he could quote at length from books read many years previously, memorising things down to the last detail. He had great determination and once his decision was made he would never give up, but behind the hard determination of going forward there was charm and kindliness. Those who came in contact with him however hard he might have been, always admired and respected him.

His sporting and his social life were as much a part of him as his business life and his hospitality was renowned. Each was complementary to the other. All the people he met and all the people who worked with him played their part. If at times his influence on them was greater than theirs on him, then that was their good fortune. He never forgot a helper and he was very generous.

By his first marriage there was one son, Richard, who is now with the Company, and from his second marriage to Esther, who survives him, he had two children, John and Jane.

He loved his family deeply and at no time did he forget his near relations, and maintained a close interest in their welfare.

In giving this Lecture every effort has been made on my part to convey a true story, which is my own interpretation of what I know.

I would like to thank all those who have assisted me, particularly members of the family, and Mr. F. K. Poulton of The Fairey Aviation Company, who, with Miss E. L. Burns (Sir Richard Fairey's private secretary for 35 years) have helped me to correlate all the details.

A vote of thanks to the Lecturer was proposed by Sir Frederick Handley Page, C.B.E., F.C.G.I., Hon.M.Inst.T., Hon.F.I.A.S., Hon.F.R.Ae.S.

Sir Frederick: What a fascinating story they had listened to and to him it was extremely interesting to see those old biplanes; they looked so much better than the things they had today. He thought that the Fox looked extremely nice, with those nice clean lines. It was a pity that they had not seen also some contemporary aircraft of that time, from which the Fox was such a great break away. After the First World War, back came all the heroes determined that they would have all the instruments, all the navigation equipment, gun gear and everything else; and so they had the era of the "flying Christmas tree." This was not the occasion for propaganda because it might excite the admiration of, or it might be an inspiration to, those people who felt they had something to live up to.

He was interested in the modesty of Mr. Hall when the lecture was given, as he so casually mentioned at first that he was the young "kid" brother, brought about by fate. Too modest; that was the trouble with all of them in the Aircraft Industry, hiding their lights under a bushel.

He had been greatly fond of old Dick Fairey and he did not think one could ever pay a greater tribute to him than to say that he was your friend, and he was a real friend. They had many battles together, battles against all the difficulties one had to deal with in facing a government department. Anybody who had any thoughts on that he would like to refer them to the second chapter of Ephesians in which St. Paul said, "We wrestle not with flesh and blood but with the spirit of wickedness in high places." Very remarkable, nearly two thousand years had passed since then and great improvements were supposed to have taken place in the world at large and in the way in which they addressed themselves and others, but the words of St. Paul still held good today with ever-increasing emphasis—particularly when one was told one must rationalise oneself, whatever that meant.

He believed that if Richard Fairey were alive today he would be against the great deal of nonsense which was talked about the future of aviation. They had too many scientists in this business. Today, if an experimental development were successful, it was spoken of as being immediately available for service operation. What the scientist had to learn was that progress was made by the improvement of small things such as micro-switches, not fundamental aerodynamical advances. For example if a test flight were being carried out for two, three or four hours and the lights started flickering and something went red, one came down thinking, well all our great aerodynamical prognostications are going wrong; actually, nothing was wrong except the micro-switches.

He felt that Fairey would have looked askance on a lot of those hasty scientific pronouncements, which seemed to indicate that manned aircraft were over and that they were going to see a future only with something which was fixed, with no brains at all, no action on its own kind and a mere automaton. He believed that irrespective of how mankind dealt with the problem of air defence and offence, man's brain would still be a dominating feature in aviation for many a long year to come. As was said in Ecclesiastes: "The race is not to the swift or battle to the strong but time and chance happeneth to us all." He believed that for many a long year to come the Royal Air Force would play a very dominating part in using manned aircraft.

He felt greatly honoured at being present that evening to help in honouring the memory of a very old friend. No one could have given a more satisfactory account and with greater interest than Mr. Geoffrey Hall. They were indeed fortunate in having so worthy a successor to their old friend Dick Fairey and he was sure they would give a very hearty vote of thanks to Mr. Geoffrey Hall.

Sir Arnold Hall, closing the meeting, said that they had had a sketch, drawn in a sensitive way with many intimate touches, of a great human being and they were grateful to Mr. Hall.

Stress Corrosion—The Engineer's View*

by

P. H. WALL, A.M.I.Mech.E., A.F.R.Ae.S.

(Handley Page Ltd.)

1. Introduction

Of all those forms of corrosion with which the engineer must deal, such as atmospheric corrosion, galvanic and fretting, stress corrosion is perhaps the most difficult to understand, to predict and to prevent.

Unlike that other troublesome characteristic of metals, namely fatigue, which also defies exact analysis, it is caused by static tensile stress acting in a corrosive environment (in many cases, the atmosphere). This may be due to internal residual stress or externally applied assembly stress and under such circumstances the possibility of stress corrosion occurring is ever present and is not necessarily removed by the cessation of the working loads.

Most alloys are susceptible to some degree ranging from those which suffer in practice to those which only exhibit the phenomena under exaggerated laboratory conditions. Some examples are railway locomotive boilers, stainless steel construction, commercial spot-welded construction and, of course, aeroplane structures in light alloy.

The advent over the past fifteen years or so of the higher strength light alloys of the Al-Zn variety and their pronounced susceptibility has brought the problem to the notice of the aeronautical engineer, sometimes forcibly so, although cracking has occurred with the Al-Cu alloys but to a lesser degree.

It may be useful therefore to consider the problems of the engineer who has a range of materials from which to choose, among which are those known to be susceptible to stress corrosion. For one reason or another, some of which will be discussed, he adopts such a material. It will then be seen what means he must use in design and manufacture to avoid trouble. Finally, we will consider briefly the implications if his attempts to solve the problem are not completely successful. Such an exercise will inevitably raise questions which only the metallurgist can answer.

Firstly, let us consider what the metallurgists have to say about stress corrosion.

2. The Mechanism of Stress Corrosion

The acceleration of the rate of corrosion damage by static stress has been defined by Harwood as stress corrosion, and stress corrosion cracking as the limiting case when spontaneous cracking appears as the combined result of stress and corrosion. He further states that the term should be reserved for those cases in which no significant corrosion would have occurred in the absence of stress[1].

Sutton has stated[2] that in the action of stress corrosion there is a greater deterioration in the properties of the material and greater damage as the result of combined static stress and exposure to corrosion than the simple added effects of each applied on its own. Fig. 1 shows the effect of stress corrosion and corrosion alone upon the strength of a material[12].

The phenomenon itself would appear to range from those cases in which corrosion plays the major part (and the applied stress is the last straw!) to those cases, usually met in aeronautical engineering, in which the corrosion is not evident and the damage is caused primarily by the applied stress. The latter case, in the extreme, where no corrosion occurs is stress cracking as distinct from stress corrosion cracking. In practice it is often hard to distinguish between the two forms, and indeed some metallurgists claim it as stress corrosion. In some of the examples to follow it could be said that they are of stress cracking, but they are included nevertheless.

The actual mechanism of the effect, although evading a precise and general definition, appears to be as follows: corrosion due to atmospheric conditions or to elements in the environment of the metal causes surface pits and fissures to appear and embryo cracks. These may be intergranular or granular, according to the material. The effect of the tip of the crack, the radius of which is exceedingly small, combined with a static tensile stress normal to the plane of the crack, is to produce a stress concentration, which leads to localised deformation, embrittlement, and then extension of the crack. This action ruptures any protective film which might form at the base of the crack and by its tearing action exposes more unprotected material to the corrosive influence. The base of the crack is anodic and a current flows from it to the undamaged surface setting up further corrosion which, if acting at a greater rate than the formation of any protective film, leads to a further penetration. This in turn causes further stress concentrations and so the process continues. This will continue until the cracking ceases due to relaxation of the static stress or until the complete failure of the material.

Figure 2 illustrates a cross section through a crack while Fig. 3 shows its appearance on the surface. Surface conditions which are favourable to intense localised attack are those of large cathodic areas and small anodic areas. These may be the result of differences of structure between the grain bodies (cathodic) and their boundaries (anodic), localised deformation of the boundaries, or local rupture of surface films due to strain.

This description of stress corrosion cracking is a very general and simplified account based on current thinking among metallurgists. However, the position is still far from clear in all cases as to the precise reasons for cracking under static stress.

*A Lecture given to the Society on 13th January 1959.

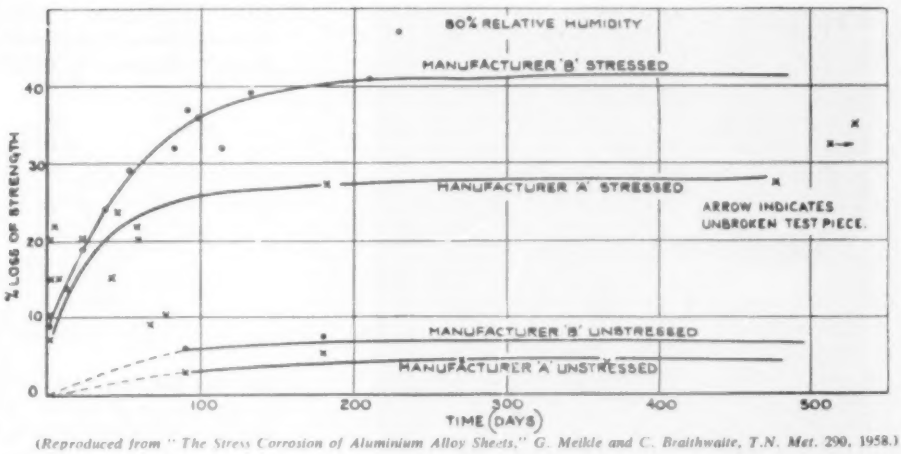


FIGURE 1. Percentage loss of strength of stressed and unstressed DTD.646 from two manufacturers.

(Reproduced from "The Stress Corrosion of Aluminium Alloy Sheets," G. Meikle and C. Braithwaite, T.N. Met. 290, 1958.)

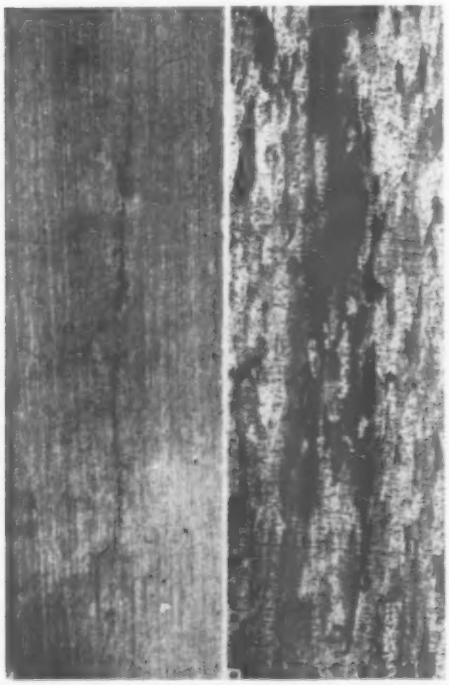
For example, Hérenguel has demonstrated that with certain of the aluminium - zinc alloys inter - crystalline fracture occurs when the metal is stressed in a vacuum. The tendency was dependent upon the ageing time at room temperature. According to Perryman ageing for long times at higher temperatures resulted in materials with greater resistance to such cracking[3]. This is worthy of note and will be discussed again later.

A similar type of cracking has also been observed in an Al-4 per cent Cu alloy. Here, creep due to shear in certain of the grain boundaries when the metal is under stress has led to a brittle fracture along the grain boundaries normal to the applied stress direction. Fig. 4 shows such a fracture in an Al-4 per cent Cu alloy aged at 190°C which failed after 231 hours at $4\frac{1}{2}$ tons/in.^{2} at 190°C[4].

The testing to which workers in this field subject their specimens differs. Some use various corrodents according to the material and apply stress as a straight tensile stress. Others, mainly the British workers on light alloys, use salt water as a corrodent applied for a few minutes in every hour while the specimen has a bending moment applied. One particular method of mechanical testing is known as the "Black test," after the metallurgist of that name, in which the test specimen is subjected to a constant bending moment, when supported across an open channel, by means of extension members clamped to the specimen bearing weights at their extremities.

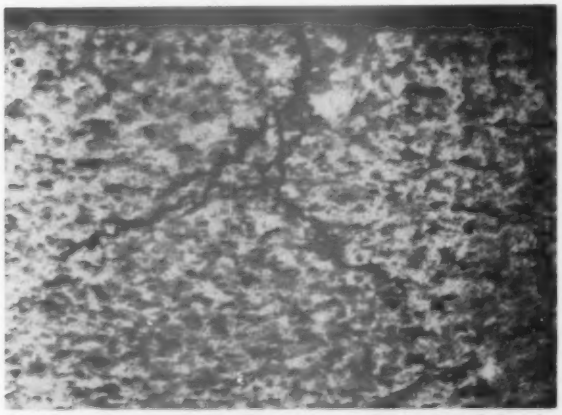
The application of a corrodent in this way is naturally in order to bring about results within a reasonable time, perhaps a time limit of say three months. Some results, however, have been obtained with the "Black test" carried out in sheds open to the atmosphere but giving protection to the specimens against direct exposure to rain, and so on.

For a given corrosive environment the relationship between stress, which it should be remembered, is the sum of external applied stress and internal stress, and the time to failure is such that the greater the stress the less the time to failure.



(Reproduced from E. H. Dix, Transactions of the American Society for Meta's, 1950, p. 1078.)

FIGURE 2.



(Reproduced from E. H. Dix, Transactions of the American Society for Metals, 1950, p. 1079.)

FIGURE 3.

(Reproduced from A. H. Sully and H. K. Hardy, Journal of the Institute of Metals, 1954, Plate XLII (Fig. 3) preceding p. 281.)

FIGURE 4.

Figure 5 shows results of tests[5] on DTD.683 with and without Cr present. The favourable results depicted here for the Cr bearing material were subsequently discounted. It is of interest to note, however, that Dix maintained that Cr has beneficial results[6]. Nevertheless the curves are typical in shape, the actual scale of values varying according to the material and its state at the time. As can be seen, a certain critical stress occurs below which the time to failure is infinite.

There is some evidence that the major effect of the stress in the actual cracking occurs just before failure

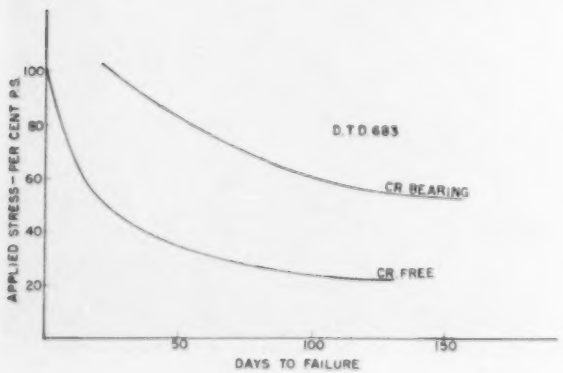


FIGURE 5.

Corrosion time without stress (mins.)	*Corrosion time with stress* (mins.)	*Total time to failure* (mins.)	*Number of specimens* Al 7 per cent Cu Alloy
0	40	40	—
0	50	50	—
0	55	55	—
50	5	55	—
50	10	60	6
0	60 to 120	<120	3
240	< 1	App. 240	3

FIGURE 6. (Reference 7).

and that the time to failure is independent of the time of application of stress. This is shown in Fig. 6 which gives the results of some work by C. Edeleanu[7]. This was carried out under intensive corrosive conditions and one is cautious about drawing conclusions appertaining to atmospheric conditions.

Disregarding such doubts leads to the conclusion in practice that the liability of a susceptible material to crack should be based upon the time when, in the course of manufacture, it appears in its final form and is first exposed to a corrosive environment (such as may occur when lying about in the machine shop unprotected). The time during which it is assembled with any consequent built-in stress is only part of the time which must be taken into account.

Reverting to the mechanism of cracking it is apparent that if there is any directionality in the grain then a crack is more likely to develop and propagate along the grain than across it. In other words, if there is stress across the grain then there is a greater probability of cracking than if the stress is applied along the grain. This is illustrated diagrammatically in Fig. 7 which indicates how there is a more natural path for the crack along the grain than across. A further reason for the grain effect is that under longitudinal load the crystals have a greater ability to shear relative to each other and thereby relieve any local stress concentrations. It is a

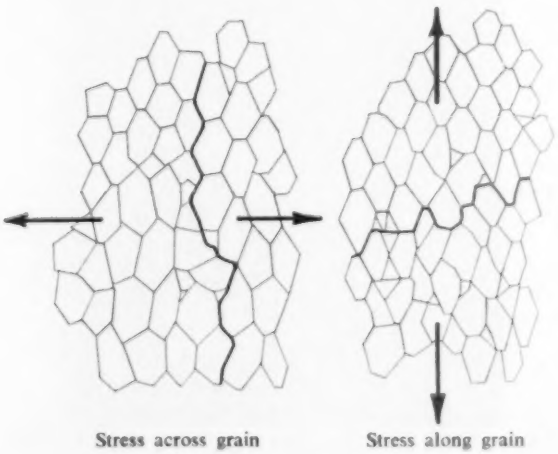


FIGURE 7.

well known fact that DTD.683 extrusions, which like all extrusions naturally have a marked longitudinal grain direction, are very susceptible to loading across the grain.

3. The Choice of Material

As stated before, most alloys of metal are susceptible to a greater or lesser degree to stress corrosion. Some of these are: —

Aluminium alloys { Al-Mg. / Al-Cu. / Al-Zn.

Stainless steel
Mild steel
Magnesium alloys
Brass.

However, many of these are only susceptible when presented to more intense corrosive media than the atmosphere and for all practical purposes the aeronautical engineer for the present has only to concern himself with the light alloys and in particular the aluminium alloys.

The magnesium alloys are, of course, very prone to atmospheric corrosion and are rarely used for primary structure, except in the case of castings, for this very reason. It is because the troublesome feature of stress corrosion occurs in the aluminium alloys which the engineer uses extensively in all forms for his structures that attention is centred upon them.

Throughout the years the strength of the light alloys has been steadily increased. This is depicted in Fig. 8 which shows how the U.T.S. and the 0·1 per cent P.S. has been increased with the ratio of P.S. to U.T.S. increasing also. It will be noted how the elongation has correspondingly decreased. The strength characteristics of DTD.683 have unfortunately not been accompanied by any corresponding increase in fatigue properties but they have been accompanied by a marked susceptibility to stress corrosion. Generally speaking this latter characteristic is confined to the bar, forging or extrusion and does not appear in the sheet form to DTD.687 due to its protective cladding.

One may well ask, at this juncture, why DTD.683 is used at all if there are such great disadvantages, and this is a most pertinent question. There is no straightforward answer. It is one, however, which in an account of the engineer's view of stress corrosion should be answered. Were the engineer to abandon the use of this material then this would be a practical solution to the problem but it is not necessarily as simple as this. Let us consider the disadvantages and the advantages, for it has some, of DTD.683 compared with its immediate predecessor L65.

In his choice of material the designer will base his decision primarily on strength to weight ratio and stiffness to weight ratio with an eye on fatigue strength. At the same time the production engineer will be standing at his elbow putting in his claims for ease of machining, forming, heat treatment, and so on.

On a weight basis the apparent advantage of DTD.683 to L65 is not always as great as would be expected from a straight comparison of their respective

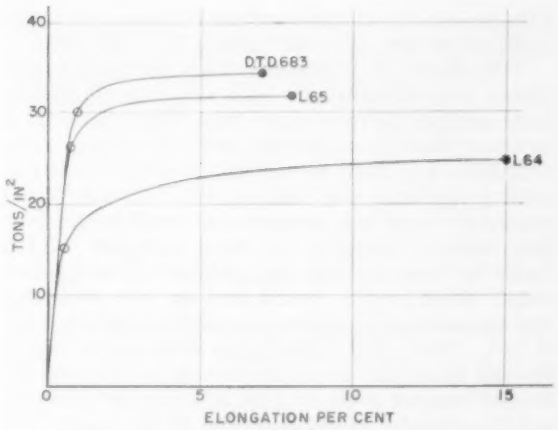


FIGURE 8.

P.S. or U.T.S. This is due to the fact that, owing to the limited ductility of DTD.683, the designer often uses greater safety factors at changes of section, large holes, and so on, to maintain the stress concentrations which these produce at nominally safe levels. Despite this, the lack of ductility and the material's consequent inability to relieve its own local high stress concentrations at grain boundaries may still lead to cracking.

In favour of DTD.683 it may be said that it has a more equable temperament under heat treatment. L65 is less amenable to the successive solution treatments that forming and correction after machining imposes. Upon second and third successive solution treatments the grain growth becomes excessive. However, the general effect of coarse grain appears to be only that of reducing the fatigue life by about 10 per cent[8]. It is also very susceptible to solution treatment temperature, great care being required to control the temperature to within the limits of the specification. Failure to do this may lead to a very great deterioration in fatigue properties. Unlike DTD.683, L65 cannot be hot quenched to the same extent and therefore residual stresses may be higher.

One who has experienced the misfortune of stress corrosion cracking during construction or while an aeroplane is in service might well even consider the use of L64. In fact all three materials have their uses and

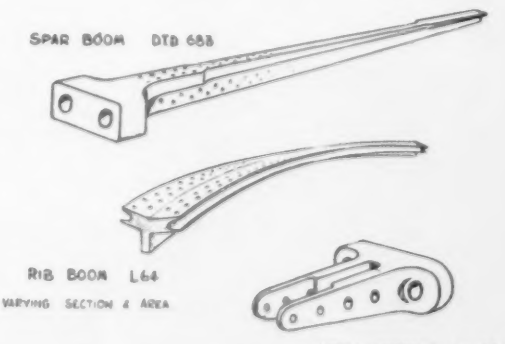


FIGURE 9.

if the variety of heat treatments could be accommodated in the shops each one could be used most effectively.

For example such members as large forgings or spar booms are generally of such size that, providing there are not too many stress raisers and no forming necessary there is a decided weight saving in using DTD.683. L65 could be used for the endless variety of small to medium size forgings which usually would require no second heat treatment and would benefit from their relative immunity to stress corrosion. Then finally for those relatively rare members of complicated shape, which require stretch forming with successive heat treatment and corrections, use could still be made of L64. Three such examples are illustrated in Fig. 9. It could be argued, of course, that in the last case the finished member could be given precipitation treatment to L65. Whether or not to do this depends upon each individual case. If the member (such as the one illustrated) is liable to stress corrosion due to high assembly stresses incurred from bad mating with adjacent structure, it may be wisest to leave it in L64 and obtain the advantages of the much better elongation characteristics in this form.

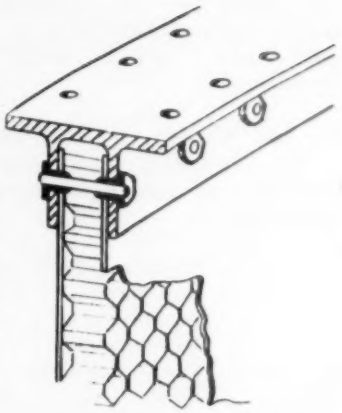
Thus, there may be good reasons for the choice of the highest grade alloys despite their temperament but the suggested use of some of the lower grade alloys is one way to avoid stress corrosion and manufacturing difficulties at the same time with a small weight penalty.

4. Problems of Detail Design

Let us now suppose that the designer for better or worse has made his choice and he has chosen to use DTD.683 or the American equivalent 75S. In what follows it will be shown how he must handle his material to avoid trouble. Firstly, let us consider the care and attention in design that is necessary.

It must be common knowledge by now that the Pi-section extrusion or bracket bolted up across the legs is the classic example of how to induce stress corrosion. Fig. 10 illustrates a common example. Here the use of bolts or spokes and nipples is potentially dangerous. Even shouldered bolts or the use of distance tubes

FIGURE 10.



is not necessarily good enough owing to the necessary tolerances on the machining of the booms, bolts, and distance tubes. This in itself does not even then allow for lack of straightness in either the boom or the web panel. In such a case as illustrated an inward deflection of the leg of the Pi of 0·010 in. produces a bending stress at the root of 10,000 lb./in.². Under these circumstances the safest way is to use blind rivets or to adopt the alternative of a fabricated section.

Another similar example is the wing joint chordwise member shown in Fig. 11 and in section in Fig. 12. This member was in use on a prototype aeroplane when cracks were found as illustrated on the same member on the structural test wing. A redesigned member whose section is shown in Fig. 13 was used on subsequent aeroplanes.

Although in its new form the member might well have been perfectly satisfactory as an extrusion it was decided as a further measure of improvement in fatigue life and in its resistance to stress corrosion that it should be made from forged bar. This is not to say that forgings are necessarily less susceptible to stress

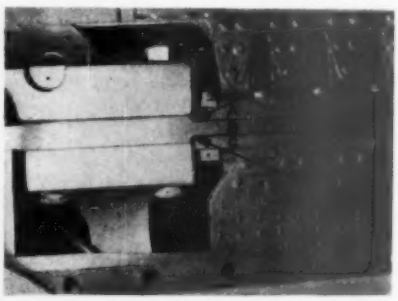


FIGURE 14 (*right*). Members A and C are radiused at the end as indicated to provide clearance between A and B, and C and B, at the ends. *See* detail diagram at foot.

FIGURE 11.

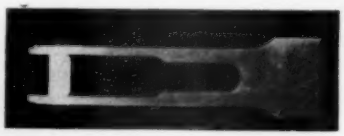


FIGURE 12.

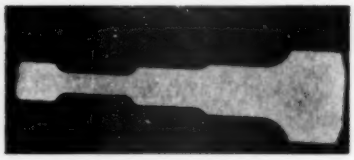
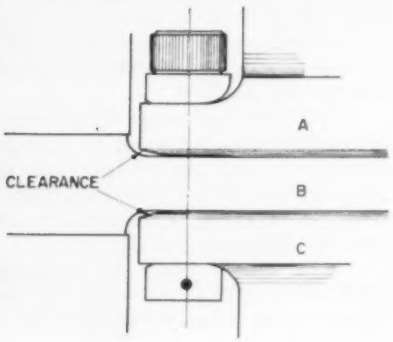


FIGURE 13.



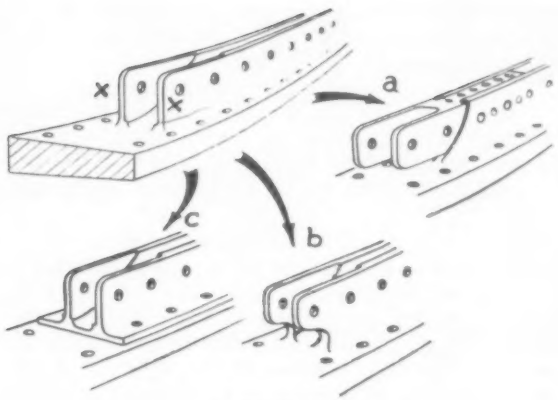


FIGURE 15.

corrosion than extrusions. Any improvement is due to the improved grain flow and any reduction in grain size. Grain which, in the extrusion, runs normal to the static stress is induced in the forging to flow transversely along the line of stress. In its new form, of course, there is no question of any built-in clamping stress as before but owing to manufacturing tolerances any lack of alignment of the member in its sandwich panel may set up transverse stresses when bolted in place. With this in mind, and to obtain relief, the main joint face is chamfered as shown in the illustration. This, together with the main joint bolts being in 1/64th oversize holes, offered a minimum of constraint.

The necessity for this latter measure is not always apparent at the time that the member is designed. But when one takes into account the curve of the wing section, the varying angle of twist along the chord and the difficulties of manufacture, the consequent probability of errors become all too obvious.

Another case in which precautions are taken to avoid assembly stresses due to lack of perfect fit is illustrated in Fig. 14. This shows the root joint of a swept spar. It was feared that the chordwise rib boom would be strained from its natural fore and aft plane when the main joint bolts were tightened if the face of the club foot was out of line. Any resulting constraint could not be avoided altogether but it was decided to relieve the rib boom by radiusing the wing joint members as indicated. This allowed a greater length for flexure and therefore keeps any assembly stresses to a minimum.

It should be noted that in turn, this radius meant that the last bolt in the chordwise joint member had to be torque loaded to a reduced tension to avoid large assembly stresses being induced in the joint members.

Sudden discontinuities as in Fig. 15, which shows a rib boom which is stretch-formed to shape and then has parts of its vertical legs removed at the intersection with spar boom, are best avoided. The probable high shear stresses which will exist on section *XX*, particularly if the member for one reason or another has not been adequately stretched during forming, will result in cross grain tension at the free edges exposed by the cut-out. To avoid this a generous radius should be maintained, as in Fig. 15(*b*). In one such case in

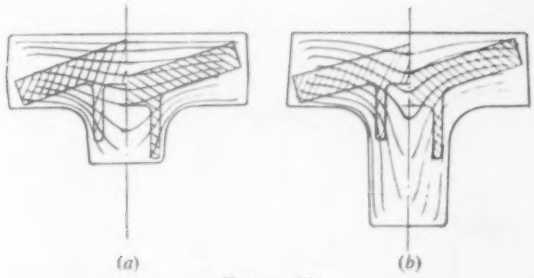


FIGURE 16.

practice a separate Pi-section made in L65 was the only answer, as shown in Fig. 15(*c*).

Typical of some of the consideration that must be given to a forging is the case shown in Fig. 16. This is a T-section which when assembled in the aeroplane carries transverse tensile working loads in all three legs. Further, owing to its curved and twisted shape, like previous examples it may well refuse to mate exactly with its fellow members and thereby experience bending moments in some or all the three legs. To obtain the benefit of using forged material the grain in the legs should as far as possible lie in the longitudinal direction of any applied tensile stresses, whether they be working loads of a variable nature or static stresses due to assembly. Fig. 16(*a*) shows how with a minimum size forged bar the grain flow in the top legs is more or less satisfactory while that in the lower leg, especially at the root, is transverse. This may be rectified by extending the leg of the forged bar as in Fig. 16(*b*). The greater flow of material to fill the greater die space results in a better grain direction, but now the top leg at the root tends to suffer. Under such circumstances a compromise must be sought with priority granted to that part of the member which is the more highly loaded in service.

Figure 17 shows another variant of the Pi-section in a main spar boom. As stated previously, unless the tolerances on machining the boom and the web, which is two forged plates back to back, together with the tolerance on straightness, are kept so small as may be impracticable there is the danger of clamping stresses

FIGURE 17.

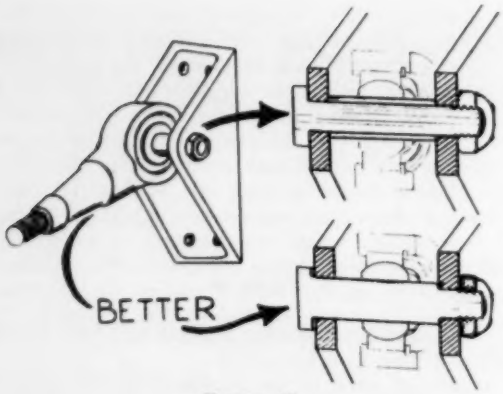


FIGURE 18.

(or their reverse) in the legs of the boom. The solution shown is to use adequate tolerances to allow for lack of straightness and to use shear pins in place of bolts. The pins are titanium in this case, secured by split pins over a plain washer.

Another fairly common example in which there exists the possibility of built-in stress across the grain is that of the hinge bracket assembly such as in Fig. 18. The solution suggested is self-explanatory. Care must be taken that the hinge pin is dimensioned from head to shoulder such that in the worst case of the bolt on its lower limit and the bracket on its upper limit there is no interference between the head of the bolt and the bracket.

It was stated earlier that the phenomenon of stress corrosion is difficult to predict. This means that not only will it occur when it is not expected but, such is the perversity of its nature, it may not occur when it is most expected. A case in point is the screw, or bolt, machined from DTD.683 bar with a machined thread. Here one has all the necessary conditions, high static tension across the grain at the root of the head or at the stress concentrations at the root of the threads. But as Meikle shows[9], this does not necessarily occur in DTD.683 machined bolts and its occurrence in screws of the Phillips type may be postponed indefinitely by the use of jointing compound.

Another case which may well be similar to that of the bolts is that of the clamping segments in a V-flange pipe joint. This is depicted in Fig. 19. To the author's knowledge no cases of stress corrosion cracking have yet occurred, but nevertheless it is suggested that if these parts are made from a susceptible material then both

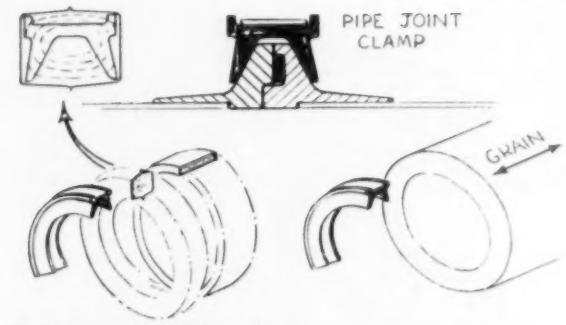


FIGURE 19.

consideration of stress corrosion and of fatigue require some such solution, as shown, in which the clamping segment is made from a length of extruded bar which is then forged before machining to shape. In this way, a better transverse grain flow should be obtained.

An interesting example of stress corrosion cracking is shown in Fig. 20. This tension member made from DTD.683 bar formed part of a test rig structure. Failure occurred at a nominal stress across the hole of 21,000 lb./in.^{2} after 60 days, subsequent to the application of 12,000 lb./in.^{2} for 390 days. The bending stress across the grain at the end of the lug plus atmospheric corrosion caused a crack, the extent of which is denoted in Fig. 21 by the lighter area. The subsequent failure then of course led to the two failures either side of the hole and complete collapse.

Another interesting case is that of the fork fitting of Fig. 22. The items shown were machined from DTD.683 bar with the grain, as would be expected, running along the legs. When assembled and bolted in place it was found that the legs were cracking down the grain as can be seen in the figure. This presumably is due to transverse bending occurring when the bolts are tightened. This was a rather disconcerting example. Subsequent parts made from forgings appear, so far, to be immune from cracking.

5. Problems in Manufacture

Having thus briefly considered the use of DTD.683 in design details let us proceed to workshop technique. In this the primary aims are: —

(*a*) Care in assembly to avoid high built-in stresses.
(*b*) Suitable methods of forming to avoid high residual stresses.

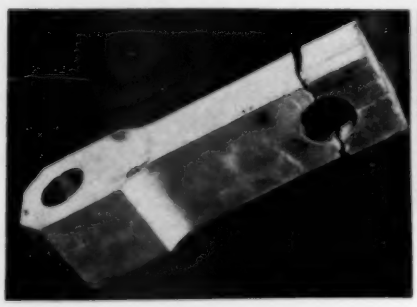


FIGURE 20 (*left*).

FIGURE 21.

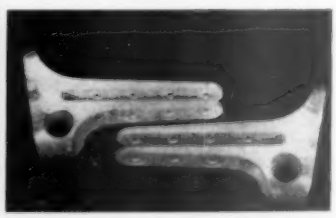


FIGURE 22.

(*c*) Suitable heat treatment to avoid residual stresses and to reduce the susceptibility to stress corrosion or to otherwise change the characteristics of the material to the same end.

(*d*) Suitable protective treatment.

Whereas (*a*) and (*b*) are primarily the responsibility of the production engineer, (*c*) and (*d*), particularly (*c*), require the co-operation of the designer.

5.1. CARE IN ASSEMBLY

Intelligent care on the part of the fitter can do much to overcome any deficiencies of detail design. For example, in many of the cases quoted, selective assembly of mating parts, such as shouldered bolts, distance pieces, and so on, would prevent large assembly stresses.

Some appreciation is required of the type of load that particular fastenings carry. It is necessary to avoid the excessive tightening of bolts whose sole purpose is to carry shear. All too often it is thought that no bolt should pass inspection unless it is really "granched" tight.

In certain cases where the assembly stress is particularly susceptible to bolt tension the use of torque spanners should be specified.

5.2. FORMING TO AVOID RESIDUAL STRESS

Although great forethought in detail design and equal care in assembly may be used, these measures will be only partially successful if the members concerned have high residual stresses due to incorrect forming or heat treatment.

Figure 23 is a simple illustration of the cause of residual stresses due to incorrect forming technique. The diagrams at the top show first of all on the left the normal linear stress distribution of a member during bending while within the elastic limit. As the bending action is increased the maximum stress changes from 1 to 2 and the distribution is no longer linear as outer fibres exceed the elastic limit. When released the member springs back, the outer fibres becoming loaded in the opposite sense as they now restrain the inner fibres from returning elastically to their original state. The surface residual stress is such as 3, which if of sufficient magnitude will create a breeding ground for stress corrosion. If before this stage an overall tension is applied (as is normally used) such as to pull all the

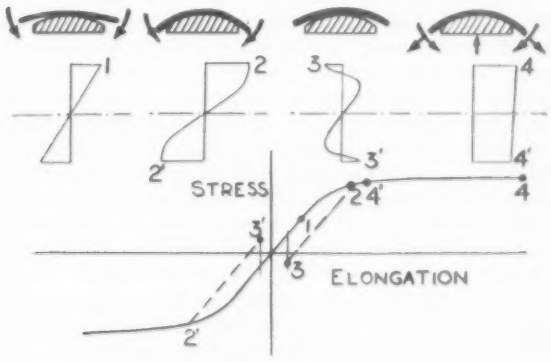


FIGURE 23.

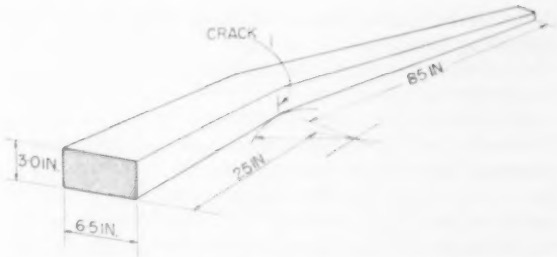


FIGURE 24. DTD.683 bar bent in solution-treated condition.

cross section into the plastic range with resultant stresses, as 4 and 4′, then practically all the tendency to spring back is removed and with it the resulting residual stresses.

This merely demonstrates the importance of giving the material an adequate stretch when forming. However, this treatment may, in the case of rather complicated members, require successive solution treatments between stretches before the full form is obtained. In such cases there may be advantages in the use of DTD.683 as opposed to L65 because, as mentioned earlier, the latter responds unfavourably to successive heat treatments.

A good example of stress corrosion cracking due to bending a bar of DTD.683 in the solution treated condition (no stretching) with consequent spring back and residual stress is shown in Fig. 24. Here the trouble was avoided by forming in the annealed condition.

In practice, it is rare that the material to be formed is of constant cross sectional area. This means that, to avoid under-stretching the larger area and over-stretching the smaller, the member must be rough machined to approximately constant area. It is then stretch-formed and finally machined to size. All this naturally demands close liaison between the designer and the production engineer at the design stage to ensure that the design lends itself to such procedure.

Another method of reducing or eliminating residual tensile stresses at the surface is to induce compressive stresses by shot peening after final machining. In this process the surface of the material is bombarded by lead pellets in a similar manner to sand blasting, the impact of which expands the surface metal all over and thereby sets up a compression in the outer skin.

In all the examples quoted in Section 4 it will doubtless be noted that no mention has been made of trouble with DTD.687. Its relative immunity to this form of corrosion is claimed to be due to its protective cladding. Such however may not be the case if, in the future, stainless steels are used for skinning. Trouble can be expected here with the local built-in stresses at rivet heads or spot welds. Leading edges will not suffice if merely rolled to shape without adequate stretch forming. Thus without care stress corrosion problems may be more widespread than at present.

5.3. HEAT TREATMENT

Various workers in the field of stress corrosion have demonstrated that the susceptibility of the current light

alloys varies according to the heat treatment. The controlling factors are: —

(*a*) Solution treatment temperature.
(*b*) Rate of quenching.
(*c*) Precipitations temperature and time.

Meikle and Lewis show that reduction of solution treatment temperature from the normal 465°C to 435°C has a very beneficial effect while an increase to 525°C results in a marked sensitivity[10]. The S.B.A.C. report of December 1956 indicates that reduction of solution treatment temperatures improves the strength characteristics of 75S up to about 16 hours of ageing after which they decline but at no time below the specified U.T.S. of 32 to 35 tons/in.^{2}.

The rate of quenching also has a very marked effect. Generally speaking, according to Dix, the quenching rate should be high to obtain maximum resistance to stress corrosion[6] (but presumably only if unaccompanied by high residual stress). This also has a beneficial effect upon the strength characteristics of the material. Fig. 25 shows how the U.T.S., 0·1 per cent P.S. and equivalent strength when under influence of stress corrosion varies with the quenching rate of 75S[6]. It will be seen that with the Cr bearing material the strength falls off with reduction in quenching rate and the sensitivity to stress corrosion increases. The effect is similar with the non-Cr material except that it is not so sensitive to quenching rate, and it does not exhibit increased resistance to stress corrosion with very low quench rates as does the former. This is of no practical importance, however, as the strength properties at these low quenching rates are so low.

However, despite these apparent advantages of high quenching rates they are not always obtained in practice. Large forgings if cooled too rapidly will contain high residual stresses which will outweigh the reduction in stress corrosion susceptibility. In such cases the greatest benefit is obtained with a boiling water quench which will prevent high residual stresses and yet still allow a relatively high U.T.S. and P.S.

A case in point is shown in Fig. 26 which illustrates a forged propeller blade[6]. The residual stresses imposed when the central boring operation was done led to a crack forming and then complete breakage. This was subsequently overcome by a boiling water quench.

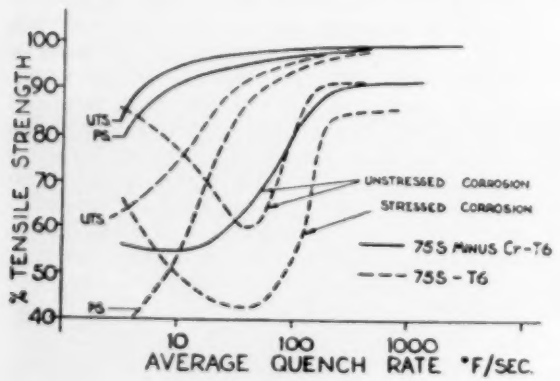


FIGURE 25.

FIGURE 26.

(Reproduced from E. H. Dix, Transactions of the American Society for Metals, 1950, p. 1081.)

Figure 25 shows that at the lower rates of quench the non-Cr material retains a higher value of strength than does the Cr material. This shows the desirability of having forgings made from the non-Cr material.

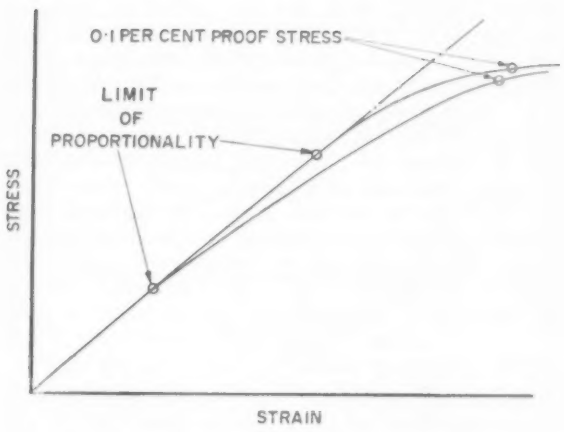
On the other hand, extrusions should be able to obtain all the benefits of a cold water quench with the highest strength characteristics and resistance to stress corrosion, particularly if stretched to remove any residual stresses. Therefore, either the Cr or the non-Cr material may be used in this case.

Up to the present time the DTD.683 specification has been framed in broad terms and permits the use of Cr up to 0·25 per cent at the maker's discretion. In view of the differing characteristics of the Cr bearing and the non-Cr bearing material and the different uses to which they could be put, it has now been decided to raise six different specifications. The general specification DTD.683A is now replaced by the following: —

DTD.5024—Al-Zn-Mg-Cu-Mn. forgings		Group 1
DTD.5034— „ „ „ „ Cr. forgings		
DTD.5044— „ „ „ „ Mn. bars and extrusions	up to 10 in.	Group 2
DTD.5054— „ „ „ „ Cr. bars and extrusions		
DTD.5064— „ „ „ „ Mn. bars and extrusions	up to 6 in.	
DTD.5074— „ „ „ „ Cr. bars and extrusions		

All having the same order of strength characteristics.

High Duty Alloys carried out investigations[14] on the effect of quenching rates and media upon the mechanical properties of RR.77, with particular reference to the limit of proportionality. It was thought that if this limit could be reduced with little change in U.T.S. and P.S. it would reduce residual stresses and stress concentrations in the material with improved resistance to fatigue and stress corrosion. This is a very worthwhile path of research. The results of their tests are given in Fig. 27. It will be seen that the oil quench, although at room temperature, gave one of the two lowest values for the limit of proportionality and a corresponding low value of residual stress. The boiling water quench, although giving the same low value for the limit of proportionality, resulted in higher residual stresses.



	Tons per sq. in.			
Quench medium −°C	*Max. Residual Stress*	*0·1% P.S.*	*U.T.S.*	*Limit of Prop.*
Water 85°	−9·2	29·5	33·3	21·0
Salt 180° then Water 85°	−1·5	27·0	31·0	14·0
Oil room temp.	−1·8	28·0	32·6	11·0
Water 100°	+4·6	28·1	32·6	11·0

FIGURE 27. All specimens are forgings in RR.77 solution-treated 4 hours at 465°C. Aged 12 hours at 135°C.

Meikle and Lewis, and Braithwaite have shown[10, 12] the very beneficial effect of increase of ageing time or temperature, particularly the latter, on unclad DTD.687 and DTD.546 and on DTD.683 and RR.77. Earlier Hérenguel[3] drew attention to the same fact.

Figure 28 illustrates how the life of DTD.683 specimens stressed to 90 per cent U.T.S. varied with ageing time and temperature. These results should be compared with the required ageing temperature of 135° ±5°C for not less than 12 hours in the DTD.683A specification and the 121°C for 24 hours in the 75S specification.

The effect of ageing time and temperature on the U.T.S. and 0·1 per cent P.S. of 75S[13] is shown in Fig. 29. Here the gain in strength with time is shown and also the loss of strength with increase in ageing temperature. Although the curve for 130°C has been omitted for clarity it can be seen that by increasing the ageing temperature to 150°C there is a loss of strength of something less than 5 per cent. This is to be compared with the very marked increase in resistance to stress corrosion shown in Fig. 28.

It is unfortunate that these two pieces of evidence are obtained on two different materials which, although complying with a similar specification, are not strictly comparable. It could be argued therefore that although there is ample evidence of the beneficial effects of higher ageing temperatures or resistance to stress corrosion it is not known exactly the penalty to be paid in strength.

5.4. PROTECTIVE TREATMENTS

To come now to the last method mentioned of dealing with the phenomenon, that is the one of protective treatments. Evidence on this score is disappointing. Table I[11] shows the comparative improvement in stress corrosion "life" with different protective treatments.

TABLE I
PROTECTIVE TREATMENTS

Treatment	*Worst life on test as a ratio of standard test unprotected*
2 coats Araldite 985 stoved (2 hrs. at 120°C)	×1·8
2 coats Araldite cured at 20°C	×1·0
Zinc shim on tension face	×1·6
Vapour blasted surface	×0·2
Zinc spray	×0·4
Aluminium spray	×1·2
Lanoline DTD.663	×3·7

6. Afterthoughts

Let us now suppose that, despite all the designer's forethought and the craftsmen's care, cracks appear in the aeroplane structure during assembly or even after entry into service. This naturally can be a disturbing state of affairs, the degree of which is dependent upon whether or not the failure occurs in a statically determinate or in a redundant and "fail safe" structure.

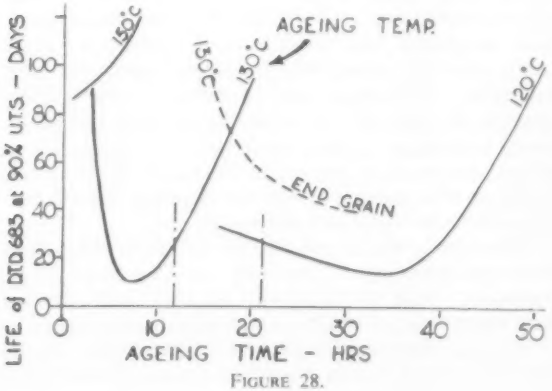


FIGURE 28.

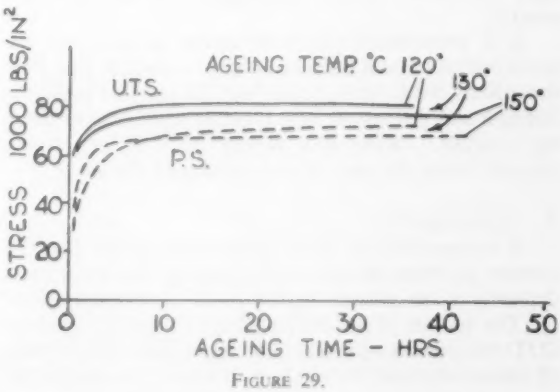


FIGURE 29.

Under these circumstances the engineer having sought the cause of the trouble and its remedy is then apt to ask himself: —

(*a*) If I apply this remedy to aeroplanes which are not yet cracked can I be sure of obtaining sufficient stress relief to come below the "threshold" value which gives me infinite life?

(*b*) To what extent is the damage cumulative? Consider Fig. 30. Assume the original built-in stress is P_1, then the potential life of the member is T_1. However, after time T_2 say, the stress is reduced to P_2 when the potential life should be T_3. The question which then occurs is whether this life will in fact be achieved, or will the life be something less, such as T_4, owing to the "extra damage" due to stress P_1 acting for time T_2?

(*c*) If a crack does appear at what rate will it propagate and how frequently should inspections be made in order to catch it before it goes too far?

The answer to (*a*) lies entirely within the jurisdiction of the engineer and relief may be obtained by slackening of bolts, easing the fit of mating parts or other such methods. As stated before if there are large residual stresses in a member due to its forming during manufacture then only partial success will be achieved.

If we believe the results in practice of Edeleanu quoted in Section 2, then the conclusion is that the answer to question (*b*) will be that the completed life will be dependent upon the stress at the time of failure. In other words when the stress in Fig. 30 is reduced from P_1 to P_2 the new life is T_3.

While considering the "fail safe" aspect of structures containing members liable to stress corrosion it may be of interest to consider the following case. It concerns a Pi-section which showed evidence of cracking due to clamping loads across the legs. Each leg alone was capable of carrying a large percentage of the maximum design load. It was therefore argued that to cover the probability of a crack the aeroplane should be subjected to a certain limitation. This was based on the assumption that once a leg cracked the remaining leg would be relieved of its load and have unlimited life, in other words a "fail safe" structure. This outlook had to be discarded when members were found cracked in both legs, the cracks being immediately adjacent to each other.

It is improbable that both cracks appeared at the same instant of time and one is led to conclude that after the critical crack occurred the leg still retained sufficient strength and stiffness at least until such time as the other leg cracked. What this period time is, of course, depends upon the rate of propagation of the crack.

7. Conclusion

It is inevitable in such a discussion as this that the current problem should revolve around the merits and demerits of the present highest grade aluminium alloys.

The advent of the Al-Zn alloys to the specification DTD.683 and its equivalent has highlighted the problem of stress corrosion to which most alloys are susceptible

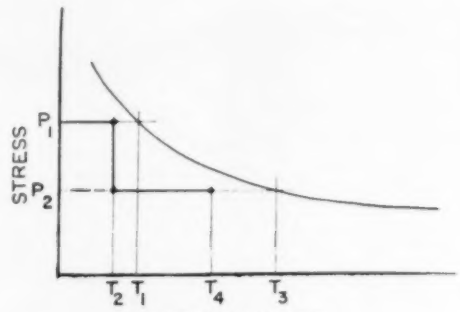


FIGURE 30.

to some degree or another. Their marked susceptibility, particularly when stressed across the grain, renders the use of these Al-Zn alloys in certain shapes and sizes a very difficult design and production problem.

At the moment this is one of the penalties, and there are others such as resistance to fatigue, which the engineer must accept in his quest for higher strength alloys.

One is entitled here to ask—is it worth it? Is the weight saving worth all the trouble caused in dealing with material of such temperament? Would it not be better to revert to the older alloys with their lower strength characteristics, but greater elongation, better resistance to stress corrosion, and greater fatigue life for a given stress?

From the point of view of weight saving it is a doubtful proposition, not only is there the excess weight (spacing bars, distance tubes, and so on) required in the detail design to avoid high assembly stresses, but there is the extra material left at critical points to avoid high stress concentrations to which the material is subjected because of its low elongation.

In these days when design and development time and effort are at a premium there are other directions in which effort can be applied with equal or greater benefits of weight saving, such as the closer integration of systems with the structure in the early design stages.

However, despite all this the material, even in its present form, has certain advantages and if used with some forethought can be placed with good advantage. It may be better from a manufacturing view point to use DTD.683 instead of say L65 if considerable forming is to be carried out. In this way the trouble consequent upon successive heat treatments of L65 is avoided. L65 is also very susceptible to overheating during heat treatment. Advantage can be taken of the specific strength of DTD.683 if its use (other than the above cases) is confined to large major members such as spar booms, where it is practicable to design down to the minimum dimensions required for strength, special care being taken to avoid any built-in stresses.

Experience so far shows that DTD.687 due to its protective cladding is relatively immune from stress corrosion. Such immunity will not exist with stainless steel sheet material which may be used in the future.

Finally, there is evidence that if the engineer relaxes his requirements for the maximum attainable mechanical

properties of U.T.S. and P.S. with DTD.683 and its equivalents and permits the material to be aged at higher temperature there is such an improvement in the resistance to stress corrosion that it would be comparable with the older aluminium alloys in this respect.

At the moment DTD specifications give the required minimum mechanical properties. In response to this and in their efforts to make sure that their range of bars, forgings, extrusions, and so on, all meet the strength requirements, manufacturers sometimes exceed the minimum requirements by too large a margin, which has been known to bring about a very marked susceptibility to stress cracking and corrosion. It may well be that fatigue characteristics are also poor.

It should not prove too difficult to not only specify those characteristics of static strength (which should lie between an *upper* as well as a lower limit) but those characteristics of equal importance such as stress corrosion strength and fatigue life on standard specimens. The extra cost would be money well spent!

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TECHNICAL NOTES

Elastic Instability of Stiffened Sheet under Compression Reacted by Shear

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FIGURE 1 ILLUSTRATES a structural problem which occurs in naval architecture, and which may also be of interest in the structural design of aircraft. Compressive loading is applied to one transverse edge of a stiffened flat sheet and reacted, not by equal compressive loads on the opposite transverse edge, but by shear forces along the two longitudinal edges. These shear forces, and the complementary shear forces acting on the transverse edges, arise from the connection of the stiffened sheet to adjacent structure. This situation arises, for example, at a ship's transverse bulkhead. The lower edge of the bulkhead is subjected to vertical loads applied by the ship's bottom structure, and these loads are transmitted upwards and outwards to the vertical edges of the bulkhead, thence to be diffused into the side shell plating.

In this condition of loading various modes of buckling of the panel are possible. Local buckling of certain areas of sheet between stiffeners might result from high shear or compressive stresses; methods are readily available for investigating these problems. A third mode of buckling, which involves overall instability of the whole panel, is also possible; the object of this note is to determine the critical conditions in which elastic overall instability of stiffened sheet may occur under this type of loading.

The notation is shown in Fig. 1. A rectangular flat sheet of breadth a, length b and thickness t has longitudinal and transverse stiffeners spaced c and d apart respectively. The sectional areas of the stiffeners are A_y and A_x, and their second moments of area (including an effective breadth of sheet) are I_y and I_x respectively. The flexural rigidities per unit length of the panel are defined as

$$D_y=\frac{EI_y}{c}, \qquad D_x=\frac{EI_x}{d}. \quad . \quad . \quad . \quad (1)$$

The edge compressive stress F is applied uniformly to both sheet and stiffeners along the edge $y=b$.

ASSUMPTIONS

(*i*) Direct stresses in the transverse direction are negligibly small.

(*ii*) The compressive stress in the panel decreases linearly from F at $y=b$ to zero at $y=0$.

(*iii*) " Stringer-sheet " theory is applicable; that is, the sheet carries both shear and direct stresses, the stiffeners carry direct stresses only.

(*iv*) All edges of the panel are simply supported.

(*v*) The deflection w due to lateral pressure q acting on a stiffened panel is governed by the equation.

$$D_x w_{xxxx}+2(D_1+D_2)\,w_{xxyy}+D_y w_{yyyy}=q,$$

in which D_x and D_y are the flexural rigidities defined; and D_1 and D_2 are coefficients which depend primarily on the torsional rigidity of the stiffened panel. The assumption is here made, for convenience of analysis, that

$$D_1+D_2=[D_xD_y]^{1/2}.$$

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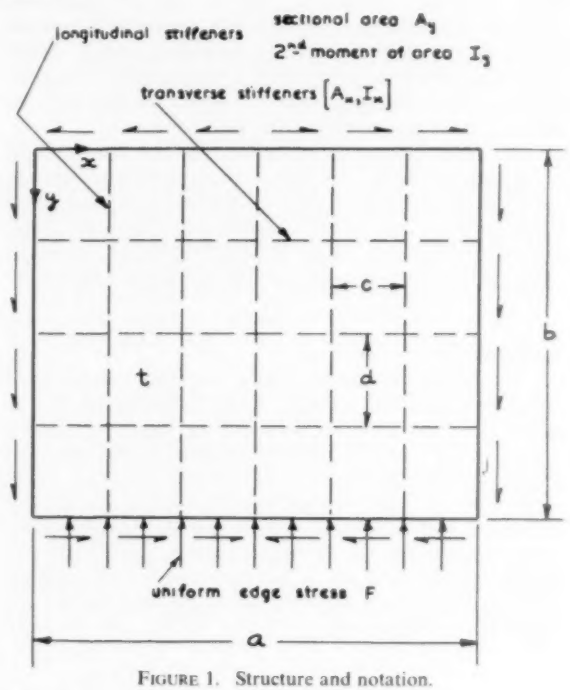

FIGURE 1. Structure and notation.

THEORY

Assumptions (*i*), (*ii*) and (*iii*) lead to the following:—

$$f_y=\frac{-Fy}{b}, \qquad f_{xy}=\frac{\alpha F}{b}\left(x-\frac{a}{2}\right). \quad . \quad (2)$$

in which f_y is the average stress in sheet and stiffener in the y direction at distance y from the edge $y=0$, f_{xy} is the shear stress in the sheet and $-F$ is the applied edge stress. α is a " stiffening factor " defined by

$$\alpha=1+\frac{A_y}{ct}. \quad . \quad . \quad . \quad . \quad (3)$$

For subsequent analysis the stresses are more conveniently converted to forces per unit length:—

$$N_y=-Ny, \qquad N_{xy}=N\left(x-\frac{a}{2}\right). \quad . \quad (4)$$

in which $N=\alpha Ft/b$.

Using strain energy analysis, critical values of N at which overall instability will occur, can be found from the equation

$$V-T=0 \quad . \quad . \quad . \quad . \quad (5)$$

in which V is the increase in strain energy of the stiffened panel during buckling, and T is the work done by the forces N_y and N_{xy}. It is readily shown that

$$V=\frac{1}{2}\int_0^b\int_0^a [D_x w_{xx}^2+D_y w_{yy}^2+2D_1 w_{xx}w_{yy}+2D_2 w_{xy}^2]\,dx\,dy. \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$T=-\frac{1}{2}\int_0^b\int_0^a [N_x w_x^2+2N_{xy}w_x w_y]\,dx\,dy. \quad . \quad . \quad . \quad (7)$$

Equations (4), (5), (6) and (7) yield critical values of N in the form

$$N_{CR}=-\frac{\iint[D_x w_{xx}^2+D_y w_{yy}^2+2D_1 w_{xx}w_{yy}+2D_2 w_{xy}^2]\,dx\,dy}{\int\int\left[y w_y^2-2\left(x-\frac{a}{2}\right)w_x w_y\right]dx\,dy} \quad (8)$$

The buckled form which satisfies the edge conditions assumed in assumption (*iv*) is taken as

$$w=\sum_m\sum_n a_{mn}\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b}, \quad . \quad (9)$$

in which a_{mn} is the generalised deflection coefficient and m and n can take all integral values. Equation (9) is then substituted in equation (8) to give values of N_{CR} involving the structural parameters and the coefficient a_{mn}. The smallest value of N_{CR} is then found by putting

$$\frac{\partial N_{CR}}{\partial a_{mn}}=0, \quad . \quad . \quad . \quad . \quad (10)$$

from which, after the necessary integration and differentiation, the following is obtained:—

$$\frac{\pi^2}{4}a_{mn}\left[\frac{(m^2\beta^2+n^2)^2}{k}-\frac{n^2}{2}\right]+\sum_n a_{mn'}\frac{2_{nn'}{}^3}{(n^2-n'^2)^2}+$$
$$+\sum_m\sum_n a_{m'n'}\frac{4mm'\,nn'}{(m^2-m'^2)(n^2-n'^2)}=0. \quad . \quad (11)$$

In equation (11) $m\neq m'$, $n\neq n'$, $m\pm m'$ is even and $n\pm n'$ is odd. β is the "modified aspect ratio" for the stiffened sheet, defined by

$$\beta=\frac{b}{a}\left[\frac{D_x}{D_y}\right]^{1/4} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

and k is the buckling coefficient for the panel defined by the equation

$$F_{CR}=\frac{b}{\alpha t}N_{CR}=\frac{k\pi^2 D_y}{\alpha b^2 t} \quad . \quad . \quad . \quad (13)$$

Equation (11) defines an infinite set of equations relating the coefficients a_{mn} to β and k. For each value of β there exists a value of k which corresponds to non-zero values of the coefficients a_{mn}. It was found that k could be calculated with sufficient accuracy by taking only the first four terms (m, $n=1$, 2) in the series defining the buckled form, equation (9).

DISCUSSION

The results are shown in Fig. 2, in which the buckling coefficient k is related to the modified aspect ratio β. The critical value of edge stress is then found from equation (13). For panels stiffened in the y direction only (a common case in practice), D_x will generally be very small in comparison with D_y, giving small values of β. The buckling coefficient in such cases will approach the minimum value of 1·88. The critical stress then becomes, using equations (1), (3) and (13),

$$F_{CR}=1{\cdot}88\,\frac{\pi^2 EI_y}{b^2(A_y+ct)},$$

or, the critical load per stiffener can be expressed as

$$P_{CR}=1{\cdot}88\,\frac{\pi^2 EI_y}{b^2}$$

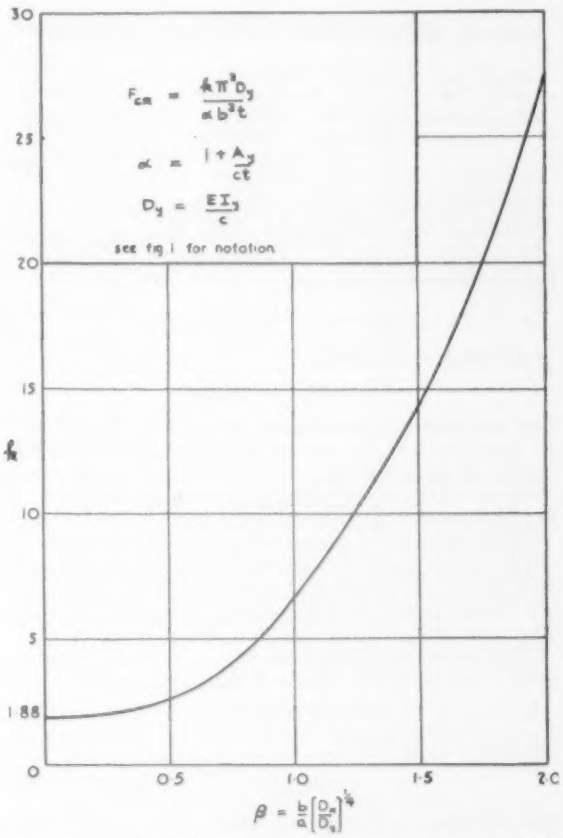

FIGURE 2. Relation between buckling coefficient and modified aspect ratio.

Thus, for panels stiffened in the longitudinal direction only the critical load under this type of loading will be at least 88 per cent greater than the Euler critical value for the same stiffeners under equal compression at both ends.

The results in Fig. 2 can also be applied to unstiffened panels under edge compression reacted by shear. In such cases $\alpha=1$, $\beta=b/a$ and

$$D_x=D_y=Et^3/12(1-\nu^2)$$

in which ν is Poisson's ratio. The critical edge stress for unstiffened panels then becomes

$$F_{CR}=\frac{k\pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2$$

in which k is found from Fig. 2.

The assumption (*ii*) of a linear stress distribution in the panel requires further comment. More exact stress analysis of stiffened panels under this type of loading shows that the stress distribution defined by equation (2) is reasonably accurate for small values of b/a. For panels which are long, in comparison with their breadth, diffusion of load out to the longitudinal edges occurs more rapidly than is indicated by linear distribution. This will have the effect of raising the critical stress for overall instability, so that the results given above will err, if at all, on the safe side. Instability under non-linear stress distributions will be considered in a further note.

Approximate Solution of Linear Second Order Differential Equations

by

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IN A RECENT PAPER[1] Collar discussed some aeronautical applications of linear differential equations with variable coefficients. Part of the paper deals with the approximate solution:

$$x = An^{-1/4} e^{-\int m\,dt} \cos\left(B + \int n^{1/2}\,dt\right) \quad . \quad (1)$$

of the differential equation

$$\ddot{x} + 2m(t)\,\dot{x} + n(t)\,x = 0. \quad . \quad . \quad (2)$$

This asymptotic approximation, which dates back at least to Liouville, has an interesting history[2]. It is widely known as the WKB approximation because of its use in quantum theory by Wentzel, Kramers and Brillouin. It has been applied to compressible flow by Imai[3].

While very useful it breaks down at the zeros of $n(t)$ and there are problems in joining solutions passing through such points. Recently[2, 4, 5] extensions of the approximation which circumvent this difficulty have been developed. This note deals with the extension due to Bailey.

This approximation can be developed from the equivalence of equation (2) and the Riccati equation:—

$$w^2 + \dot{w} + 2mw + n = 0 \quad . \quad . \quad . \quad (3)$$

where $w = \dot{x}/x$ so that

$$x = \text{constant}\ e^{\int w\,dt} \quad . \quad . \quad . \quad (4)$$

If $\dot{w}$ is written as Dw and (4) solved as a quadratic in w, the expression

$$w = \left(\frac{D}{2} + m\right) \pm \sqrt{\left\{\left(\frac{D}{2} + m\right)^2 - n\right\}} \quad . \quad (5)$$

is obtained. This is a meaningless expression since D is an operator and means nothing without an operand. We can however, obtain an approximate solution by interpreting D as

$$D \simeq \frac{1}{f(m, n)}\,Df(m, n). \quad . \quad . \quad (6)$$

A plausible choice of $f(m, n)$ is obtained by using the well-known method of eliminating the first derivative from (2). By the substitution

$$y = xe^{\int m\,dt} \quad . \quad . \quad . \quad . \quad (7)$$

where y satisfies the differential equation

$$y'' + (n - \dot{m} - m^2)\,y = 0. \quad . \quad . \quad (8)$$

The function $I(t)$ defined by

$$I(t) = (n - \dot{m} - m^2), \quad . \quad . \quad . \quad (9)$$

which is called the invariant of the differential equation, is introduced. It plays an important rôle in the classical theory of differential equations. By requiring that:

(*a*) the Riccati equations corresponding to (8) and (3) give consistent results and

(*b*) the approximation reduces to the WKB approximation when $(D/2 + m)^2 \ll n$, it is found that

$$f(m, n) = I^{1/2}. \quad . \quad . \quad . \quad (10)$$

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The approximate solutions are

$$x \simeq e^{-\int m\,dt}\, I^{-1/4}\, e^{\pm \int \sqrt{\left[\left(\frac{I'}{4I}\right)^2 - I\right]}\,dt} \quad . \quad . \quad (11)$$

The WKB approximation neglects the $\left(\frac{I'}{4I}\right)^2$ term* which, however, is the dominant term when I is small.

There are two obvious instances in which (11) is an exact solution of (2). The first case is when I is constant. In this case the WKB approximation is also exact. This class of equations is not restricted to equations with constant coefficients. It includes equations such as Bessel's equation of order 1/2

$$t^2\ddot{x} + t\dot{x} + (t^2 - 1/4)\,x = 0. \quad . \quad (12)$$

The general form for the solution of this class of equations is

$$x = e^{-\int m\,dt}\,\{Ae^{\lambda t} + Be^{-\lambda t}\}. \quad . \quad . \quad (13)$$

The exponentials can be written as trigonometric or hyperbolic functions. The second case for which (11) is an exact solution is when

$$I = k/t^2. \quad . \quad . \quad . \quad . \quad (14)$$

In this case the WKB approximation does not give an exact solution. The most important equation of this class is the well known Euler equation

$$t^2\ddot{x} + at\dot{x} + bx = 0. \quad . \quad . \quad . \quad (15)$$

If the behaviour of the differential equation

$$\ddot{x} + ct^k x = 0, \quad . \quad . \quad . \quad . \quad (16)$$

where $k > 0$,

is examined in the neighbourhood of $t = 0$, the indical equation shows that there are solutions behaving as t^0 and t. As

$$\left(\frac{I'}{4I}\right)^2 = \left(\frac{k}{4t}\right)^2, \quad . \quad . \quad . \quad (17)$$

it is much greater than I for small t.

Therefore

$$I^{-1/4} e^{+\int \sqrt{\left[\left(\frac{I'}{4I}\right)^2 - I\right]}\,dt} \longrightarrow \text{constant} \quad . \quad (18a)$$

and

$$I^{-1/4} e^{-\int \sqrt{\left[\left(\frac{I'}{4I}\right)^2 - I\right]}} \longrightarrow I^{-1/2} \simeq t^{-k/2}. \quad . \quad (18b)$$

Therefore, while the use of the positive sign gives a solution which behaves properly near the origin, the use of the minus sign does not. Bailey therefore recommends using

$$x_2 = e^{-\int m\,dt}\, I^{-1/4}\, e^{+\int \sqrt{\left[\left(\frac{I'}{4I}\right)^2 - I\right]}\,dt} \int I^{1/2}\, e^{-2\int \sqrt{\left[\left(\frac{I'}{4I}\right)^2 - I\right]}\,dt}\,dt,$$

. . . . . (19)

*Equation (1) is therefore not a consistent formulation of the approximation.

as the second solution, which is based on a well-known expression for the second solution in terms of the first.

It is unfortunate that these approximate methods are generally neglected in texts on differential equations. They are useful tools and offer a field for further study. For example, extension to higher order equations would be desirable.

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The NATO Defense College

by

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HISTORY

The College owes its origin to the early days of NATO when the first Supreme Allied Commander Europe, General Eisenhower, was confronted with the problem of finding suitably trained staff to fill the posts in the NATO organisation. He therefore proposed to the Standing Group that a Defense College should be formed to fulfil this function. This proposal was agreed and the French Government set aside part of the historic Ecole Militaire building in Paris to house the college. The first course began in November 1951, some two years after the signing of the North Atlantic Treaty and since then fifteen courses have been held, each of approximately six months duration.

The first Commandant was Admiral Lemonnier of France, who was succeeded by Air Marshal Sir Lawrence Darvall, R.A.F., Great Britain, Lieutenant General Clovis E. Byers, United States Army, Lieutenant General de Renzi, Italian Army, and Major General Estcourt, British Army. The present Commandant is Lieutenant General Ariburun of the Turkish Air Force.

The College is administered by the French Government, and the majority of the administrative staff is provided by them. The directing staff consists of four Deputies and twelve faculty advisers. All three services are represented and there are two civilian members. 75 per cent of the directing staff are from France, U.S.A. and U.K., the remaining 25 per cent being from the twelve other NATO nations.

In addition the College has its own permanent staff of interpreters, translators, draughtsmen, typists, projectionists, librarians and clerical workers.

The College building houses its own lecture hall complete with projection facilities, reference library and archives, administrative offices, committee rooms, drawing office and mess.

AIMS AND OBJECTS OF THE COLLEGE

The principal task of the College is to train selected military and civilian personnel for senior posts in the NATO structure or similar positions in their own national government organisation.

In planning the thirteenth course which I attended, facilities had been provided to enable students to gain experience under a wide range of headings of which the following were some of the most significant:—

(*a*) To accumulate knowledge of the military and non-military structure of NATO, its strength and weaknesses, and to gain a broader knowledge of some of the problems with which it is faced.

(*b*) To learn more about the countries constituting NATO, particularly from the political, military and economic aspects, and to foster friendships between the representatives taking part in the course which might later become international connections.

(*c*) To gain a broader knowledge of the SEATO and Bagdad Pacts and the uncommitted and under-developed areas of the world.

(*d*) To present opportunities for the free interchange of ideas and experiences, unfettered by local or national interests, to the mutual benefit of those taking part.

(*e*) To gain experience, by working together on set problems, of some of the difficulties of working on an international basis, at the same time learning to listen to and understand the other person's point of view.

CONSTITUTION OF THE COURSES

The number taking part in each course is limited to between 50 and 60 members in all. The courses held so far have been approximately 75 per cent military in constitution, the remainder being civilians from various government departments. They are mainly of the rank of Colonel or equivalent. On the thirteenth course, thirteen countries were represented, only Iceland and Luxembourg not participating.

LANGUAGE DIFFICULTIES

In a multi-national gathering of this sort, language differences might have been a problem, but this was overcome by following the NATO pattern. All students were expected to have a reasonable knowledge of one or both of the official NATO languages, *i.e.* French and English. Attendance at language instructional classes was compulsory except for those who were fluent in both languages. Others were segregated according to their needs and where French or English happened to be a mother tongue, study of the other language had to be undertaken. All the working of the College was carried out in these languages, and all instructions and documentation were published accordingly. During lectures, presentations and film performances both at the College and on tours, interpreters translated the proceedings through headphones for the benefit of those with limited knowledge of the language in use. This service was particularly valuable during question periods when both languages were used concurrently.

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During committee work, discussion groups and College functions, no interpreter services were available and the students had to use both languages themselves and help each other to make themselves understood.

PATTERN OF WORKING

Except when the College was away on tours or industrial visits, the normal pattern of day to day working was as follows:—

The day began with one hour of compulsory language instruction, which was followed by a lecture of approximately one hour duration. After a short break which provided an opportunity to meet the lecturer, there was a question period of approximately an hour and a quarter. In the afternoon students were engaged on committee work, either discussing the morning lecture or working on certain set problems.

This pattern was interrupted occasionally by the formation of discussion groups consisting of two or more committees amalgamated to consider certain specific papers prepared by the staff, and by the presentation of committee solutions of the set problems before the full assembly of the College.

The performance of the national films of the NATO countries usually followed the afternoon committee periods.

LECTURES

The programme of lectures covered a wide range of subjects which could be grouped under the three headings of military, political and economic matters.

The standard of the lectures was in the main extremely high, and in most cases it would have been difficult to find more knowledgeable speakers on the individual subjects.

Many eminent authorities, such as, Monsieur Spaak, Secretary General of NATO and His Excellency Ambassador van Kleffens, President of the Ninth Session of UNO, were among the lecturers.

COMMITTEES, CONSTITUTION AND TASKS

Following the pattern frequently adopted in Staff Colleges, the students were divided into syndicates or committees, each under the supervision of one of the faculty advisers of the College. On the thirteenth course the committees were composed of a chairman, secretary, assistant secretary and a few members.

The constitution of the committees was changed several times during the course to mix the students as much as possible and allow as many people as possible to have the opportunity of functioning in one of the executive positions. No two nationals from the same country were allowed to be on the same committee, and the students were mixed so that the language problem became progressively more exacting. Committee work usually took place in the afternoon and entailed working on one of the problems set by the staff. Each committee had to work independently and prepare a solution in a given time. These solutions were scrutinised by the staff responsible for setting the problem, and the salient points were discussed by the full assembly of the students at special sessions set aside for this purpose. The set problems were designed to exercise the knowledge gained during the lectures, and to encourage students to carry out further research from the extensive bibliography contained in the College Library and Archives. Each problem necessitated considerable detailed research.

DISCUSSION GROUPS

At intervals during the course the committees were amalgamated to form discussion groups, to discuss certain papers prepared by the College staff. Each discussion group was under the chairmanship of a faculty adviser and the subjects discussed were either of particular importance to the problem on which the committees were working at the time, or of particular significance in the overall scheme of the course. By this means students were able to learn from each other and interchange their knowledge and experience in certain fields.

INSTRUCTIONAL TOURS

During the thirteenth course there were three instructional tours, to Germany, and Northern and Southern Europe. Transport was provided on this occasion by the U.S. Air Force, but for previous courses other nations have provided the transport.

The objects of these tours were:—

(*a*) To gain first-hand experience of the people of these countries and learn something of the way of life, cultural background and future development potential.

(*b*) To see examples of industry and commerce in the NATO countries.

In addition to the instructional tours the College made several single day visits to NATO Headquarters and French industrial centres in or near Paris. In addition to such visits which were a compulsory part of the course, the College organised a series of optional cultural visits to places of interest in or near Paris, such as, Versailles, Malmaison and the Maritime Museum.

EXTRA SERVICES

The College was extremely hospitable, not only to students but also to the wives and families resident in, or visiting, Paris. They were invited to participate in cultural visits, national film performances and special language classes. Lectures were given outlining the purposes of the College, and the importance of NATO, and special functions were organised to foster the same spirit among the wives as between the students, particularly when the College was away on its tours. This aspect was of particular value to families going to NATO posts after the course.

The creation of the spirit of co-operation and friendship among members is one of the objectives of the College, and as a post-graduate service the College keeps all members informed of its activities and maintains liaison between its graduates. In most member countries Anciens Associations have been formed to foster the interests of the College and the North Atlantic Treaty Organisation, in addition to ensuring that visiting members of the College are hospitably received. In addition a reunion is held annually at the College in Paris at which top level NATO officials discourse on current events and developments of the past year.

CONCLUSIONS

Attending the thirteenth course was a unique experience and left a lasting impression. The pace was very intense, and the volume of information imparted was tremendous. The significant issues could be summed up briefly as follows.

The conflict of ideologies between Communism and Capitalism as exemplified by the Communist Bloc on the one hand and the NATO nations on the other, must now be considered on a world-wide basis. In the uncommitted and under-developed areas, the standard of living is considered synonymous with industrial and technical achievement, and in view of the avowed intention of U.S.S.R. to overtake U.S.A., it is by this yardstick that the progress of the struggle is judged.

The mutual fear of military aggression has resulted in

both sides devoting considerable resources of man-power, materials and technical effort to equipping their armed forces. As the West has no intention of armed aggression their forces must be maintained at a level sufficient to deter Communist aggression, but it is of vital importance that this collective effort is achieved by the most efficient means possible, so that the effect on the economies of the NATO nations is kept to a minimum. This will allow the maximum possible effort to be deployed in the economic struggle which is increasing in severity and, in view of the ruthless efficiency of the Communists, the West cannot afford to mismanage its affairs or squander its resources.

Since the final outcome of this struggle depends to a great degree on successful achievement of new technical developments, more efficient use of available resources of raw materials and power, more economic production methods and a host of kindred subjects covering both the military and civilian fields in which scientists, engineers and technicians play a vital part, the importance of their contribution must be properly appreciated and deployed.

The Mechanism and Application of Effusion Cooling

L. GREEN, Jr., Ph.D.

(Aerojet-General Corp., Azusa, California)

IN HIS EXCELLENT REVIEW of the "state of the art" of effusion cooling (p. 73, February JOURNAL, 1959), Dr. P. Grootenhuis clearly distinguishes the two mechanisms which contribute to the cooling effectiveness; namely, efficient abstraction of heat from the porous wall material by internal transfer to the effusing coolant, and reduction of the rate of external transfer of heat from the stream to the wall as a result of boundary layer injection. An observation that deserves emphasis, however, is that the first of these mechanisms is the predominant one. This fact is illustrated by the good agreement between the theory assuming laminar flow conditions (*i.e.* involving integration of the Navier-Stokes equations and the use of a one-parameter velocity-profile expression proposed by Schlichting for the laminar boundary layer with injection) and the various experiments, all of which involved turbulent stream conditions. This observed agreement indicates that the surface temperature is primarily controlled by the internal heat transfer within the porous wall and is relatively insensitive to the external heat-transfer conditions.

A similar result was recently observed by the author in experiments using values of ξ up to the order of 10^5 in the expansion section of a supersonic nozzle.[1] In this case the coolant-side porous wall temperature was measured and the stream-side value was calculated by solving the heat-conduction problem in the porous wall. Two alternative stream-side boundary conditions were used: first, that the stream-to-wall heat transfer coefficient was unaffected by injection, using the correlation of Saunders and Calder[2]; second, that this coefficient was reduced by injection according to the theory of Rubesin.[3] It was found that a twenty-fold reduction in stream-to-wall heat transfer coefficient effected only about a two-fold reduction in the calculated surface temperature ratio $(T_w-T_c)/(T_0-T_c)$, where T_0 is the stream stagnation temperature. The author thus shares the opinion of Grootenhuis that even a relatively crude assumption regarding the structure of the boundary layer with injection is adequate for the purpose of estimating the effectiveness of porous-wall cooling.

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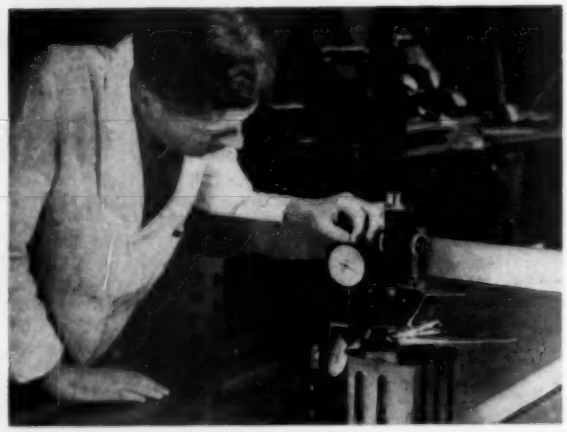
Graduates' and Students' Section

Visit to R.A.E. Bedford

The April visit of the Section was to R.A.E. Bedford to see the Wind Tunnel and Aero Flight Sections.

In an introductory talk the Chief Superintendent of Wind Tunnels, Mr. Hufton, explained the relationship between Bedford and Farnborough. Bedford now has about half of the R.A.E. Aerodynamics Department, part of the Structures Department, the Naval Aircraft Section and the Blind Landing Experimental Unit. The original idea was to move the whole of the Aerodynamics Department to Bedford, but it was eventually realised that it was rather wasteful to build at Bedford duplicates of all the tunnels already in existence at Farnborough, and so wind tunnel work is now carried on at both places.

The rest of the morning was taken up with visits to the 3 ft. x 3 ft. and 8 ft. x 8 ft. wind tunnels. The 3 ft. x 3 ft. tunnel has a maximum Mach number of 2. It is possible to see directly into this tunnel except at transonic speeds, when the liners prevent any visual observation. Unfortunately a transonic run was in progress when we were there. Mach number in the tunnel is varied by using different working sections, each with a profile appropriate to one Mach number. The tunnel was built rather hurriedly in the late 1940's to enable some supersonic tunnel work to be carried out in this country.



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Checking a Javelin model for the high speed tunnel at Bedford.

The 8 ft. x 8 ft. tunnel is a much more sophisticated affair. It has a maximum Mach number of 2·8. This tunnel, like the 3 ft. x 3 ft., is continuous, but unlike the smaller tunnel it is possible to vary the Mach number while the tunnel is running. The roof of the tunnel is a one inch thick steel plate, and the required Mach number profile is obtained by bending this plate using hydraulic jacks. The whole process is done automatically, using a punched tape to control the jacks. Various safety devices are incorporated to prevent any jack running away and breaking the plate. 80,000 h.p. is required to run the tunnel at maximum speed, most of this power being required to decelerate the air flow beyond the working section.

One of the major problems in high-speed wind tunnel design is getting rid of the surplus heat produced in compressing the air, and large batteries of cooling towers alongside the tunnels indicated the size of this problem.

The afternoon was spent in the Aero Flight Section. Here are the aircraft with which the Department carries out full scale investigations into various aspects of flight. A short film showing stall tests on the Boulton Paul Delta and spinning tests with a Javelin model, preceded a tour of the Flight Hangars. This part of the day was all too short, and only quick glimpses were possible of two P1.A's, an F.D.2, an Avro 707B and C, a Vulcan, a Beverley and various marks of Hunter, among others.

The final item was a tour of the high supersonic wind tunnel, which is under construction, and should start running next year.

It was generally felt that the visit had been well worthwhile, but that on future occasions the Naval Aircraft Section should be included in the programme.

Our thanks are extended to all those members of R.A.E. Bedford who gave up their time to show us round.—J.D.D.

Graduate Prospects

It has been suggested that current conditions in the Aircraft Industry have made it very difficult for young graduates to find the type of work in the Industry which they want. But enquiries among students at a well-known London college indicate that the position is not as bad as might be expected, although worse than at times in the past.

Most of the larger companies in the Industry send representatives to the college who interview students that may be interested in working for their company. Students who are successful at these preliminary interviews are invited to visit the companies where they have further interviews with the heads of the departments in which they are interested. In general about 50-60 per cent of these applicants are offered jobs by the companies they visit. As students often visit several companies, a reasonable number of them (eventually) find that they have three or four companies to choose from.

About one-quarter of the students choose graduate apprenticeships, the salaries for these range from £550 to £675 p.a. for a graduate with a second-class degree. For direct entry to companies the salaries offered are similar, although £800 p.a. has been offered for stressmen. Most students find that they can get employment of one kind or another fairly easily, but some have found it impossible to get the exact job they want.

Astronautics and Guided Flight Section

Many graduates and students do not appear to be aware that they can join the Society's Astronautics and Guided Flight Section merely by writing to the Secretary and applying for membership; no subscription is charged. This Section is particularly interested in encouraging the younger members of the Society and recently held a discussion meeting on rocket propellants to which it made a special point of inviting graduates. Its lecture programme which is of great interest extends over the wide and dynamic fields of missile and space technology. Unfortunately this Section has few graduate and student members at present, presumably because it is not widely realised how simple a matter it is to join the Section.

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Reviews

AGARD MATERIALS PROPERTIES HANDBOOK. Vol. I. ALUMINIUM ALLOYS. *Prepared by the Royal Aeronautical Society for the Structures and Materials Panel of AGARD. Approx. 150 pp. Tables.* NOTE: This Volume is not on public sale. Copies are distributed to various organisations in the United Kingdom by T.I.L. Room 009A, First Avenue House, High Holborn, W.C.1, and the Society's Technical Department has a number of copies which are available on loan to organisations which may be unable to obtain copies through this channel.

This review falls into two parts; first, what has been done and second, what will be done.

In building aircraft a thorough knowledge of the materials of construction is essential, and when manufacturing under licence, modifying or repairing a foreign aircraft one needs to know how one's own materials compare with those of the country of origin. Here is the data for the chief aluminium alloys used in aircraft from five sources, namely, Canada, France, Italy, the United Kingdom and the United States. Greece, Norway and Turkey do not make these alloys and other countries, notably Germany and the Netherlands are to furnish their data later. Canada modestly remarks that her alloys are the U.S. ones under different names.

The data are divided under National Sections (this is what has been done). In each National Section the physical and mechanical properties of each distinct alloy are set out in a series of sheets arranged in tabular form. The tabular forms are almost precisely similar; and an Introductory Note to each N.S. affords general information with regard to notation and amplifies such matters as designation and specification of the alloys, heat treatment, cladding thicknesses of plates, testing procedure and other information, which could not be comprised within the tabular charts. The units quoted on each chart are those of the country of origin; the wording on the charts is kept to a minimum; and a master chart is provided which lists the several notations used. Little or no translation is otherwise required.

The characteristics listed comprise chemical composition, heat treatment, physical properties, mechanical properties at room and elevated temperatures, including for the latter short time properties, recovered properties at air temperature after exposure to high temperature, and creep data. The shapes of the stress strain curves are to be inferred from the proof stress values listed by use of R.Ae.S. Data Sheets or on a similar basis.

The data on strengths are presented as *either A*, guaranteed minimum values, *or B*, 90 per cent values—10 per cent of what you buy may not be quite as good, *or C*, typical values—some other proportion of your marketing may not come up to scratch.

That is what has been done, and before proceeding we should reflect that it is no mean achievement to have done so much. Let the engineer now go on to do a little more.

If one has to construct under licence, modify or repair a foreign aircraft one needs to distinguish just four chief aluminium alloys: two contain about 4½ per cent copper, the third about 5 per cent zinc and the fourth quite a bit more zinc. In the up-to-date Cu-alloy, Mg, Si and Mn are also named partners, Mg and Si holding about 1½ per cent stock between them and Mn about ½ to 1 per cent. This alloy you can have in Canada, France, Italy, U.K. or U.S. The French call it A-U4SG (A for aluminium, U for copper, S for silicon and G for magnesium—well, well!); the Italians call it P-Al Cu 4,4 Si Mn Mg or P-AC4,4 for short (P means plastic worked); the U.S. call it 2014, and the 2 means copper (7 for zinc); the Canadians term it Alcan 26S; and the British leave you to choose from L62-65, L70-73 and DTD5010-5040 (but the final zero is borrowed from Canasta).

In the fully heat treated state of this alloy the tensile strength of the best extrusions, in kips/in.² (=1,000 lb./in.²), is guaranteed at 72 minimum by U.K. and at 68 by Italy, while France and U.S. offer 90 per cent better than 73; 0·1 per cent proof stress is above 63 (U.K.) the 0·2 per cent proof stress above 60 (Italy); while 90 per cent again will have 0·2 per cent proof stress above 66 in France or 65 in U.S. France and U.K. claim 8 per cent elongation, Italy and U.S. only 7. We all seem very sure of ourselves.

When it comes to fatigue none is quite so confident and all take refuge in data basis *C*. For failure in 10^8 cycles of plain polished bar U.S. quotes 19 k.s.i., U.K. 22 k.s.i., France 22·8 k.s.i. (that is, 16 kg./mm.²) and Italy scoops the pool with 20 kg./mm.² which is 28·5 k.s.i.

So much for L65; but L64 looms behind, and clearly both French and Italians take pride in their cooking and deplore the "all-ready-to-eat" packing in Alcans. Maybe they are right; or does it all lie in the exotic flavours? Pinches of Ti, Cr and Fe are countenanced by all, but these and the bouquet of still rarer herbs are severely rationed, while U.S. even distinguish the ingredients for extrusion from those for all other forms.

In the zinc alloys there is found much the same measurement of agreement, with *B* claims advanced about 10 per cent on *A* claims, and Mn now involved in a nexus with Cr and Ti which it would take the House of Lords to disentangle.

Summing it all up, if four nations with four alloys go on working for four years, can we suppose that they will get them clear? Well, maybe. In the meanwhile remembering the Italian excellence in the cooking of another extruded product we eagerly await their *A* claim for fatigue resistance. At present one is left an uneasy feeling that probably U.S. has made more fatigue tests than any other nation.—H. L. COX.

THE NIMONIC ALLOYS. *W. Betteridge. Edward Arnold, London, 1959. 332 pp. Illustrated. 80s.*

In 1903 the Wrights, by combining in one unit, the glider and the petrol engine, gave mankind a new freedom. Some forty years later, Sir Frank Whittle, by producing an effective substitute for the earlier power plant, thereby made possible another great advance whose potentialities, like those of the airframe, have yet to be developed to the full. In retrospect, one sees that, while the problems of the Wrights were mainly aerodynamic, those of Whittle, *inter alia*, involved both thermodynamics and chemical and physical metallurgy.

More than a century ago, Carnot, and later, others of comparable magnitude, such as Joule and Kelvin, from purely theoretical considerations, stressed the importance of having the highest possible initial temperature for the working fluid of heat engines. From pre-Newcomen to post-Parsons, a period approaching two centuries, this, for entirely practical reasons, was, in the case of the steam engine, never, in fact, high. At atmospheric pressure, as is indeed known to nearly everyone, water boils at 100°C,

but, as is certainly not known to a comparable number of people, its critical temperature, above which, regardless of pressure, it is always in the form of steam, is 365°C. This, of course, is within the capacity of wrought iron or of mild steel. Thus, until some time after the invention of the super-heater, the steam engineer had no real need for materials of the type now termed heat resisting. On the other hand, the intensive development of internal combustion engines, particularly those for aircraft, led, not only to progressive decreases in weight per horse power and to an increase in thermal efficiency but, and this, at first sight, may seem paradoxical, to increases in exhaust valve temperature. The consequential mechanical and chemical problems of this gave a very marked stimulus to the demand for heat resisting steels. This was augmented by the need for materials for exhaust-operated superchargers. Thus, when Sir Frank Whittle was developing his revolutionary power plant, one of his many difficulties was to find materials suitable for the combustion chambers, nozzles, discs and blading of his gas turbine. In the main there were available to him ferritic and austenitic steels, but while some of the latter had initially to serve his purpose, at least as far as blading was concerned, their properties were such as to limit their operating temperature to about 650°C. In the subsequent development of this prime-mover metallurgy has, of course, played and is continuing to play, a conspicuous part. In this, the contribution made by the very interesting non-ferrous alloys forming the subject of this review has been considerable indeed.

In all engineering involving the use of metals, the metallurgist and the engineer are, in a sense, partners. In most such engineering enterprises, however, the metallurgist can be described as a sleeping one unless, perchance, he suffers from insomnia. Today, if an engineer has to build a steel structure subject to normal exposure, he requires no metallurgical help. He has had it. A B.S. specification will tell him what he needs to know. On the other hand, if a gas turbine has to be produced, though there are specifications for some heat resisting materials, the engineer is hopeful that by collaboration with the metallurgist he may not only get the very best out of them, but possibly be brought into contact with something better than the best yet disclosed in current specifications.

For a number of reasons, the book that Dr. W. Betteridge, with some assistance from some of his colleagues, has produced, dealing with the class of heat resisting alloys known as "Nimonics" can be very strongly recommended. From some three hundred well written, well documented and well indexed pages, generously interspersed with many instructive illustrations, the engineer can learn of the present state of development of these remarkable non-ferrous alloys. The metallurgist is certainly by no means neglected. He is told, in some detail, how this has been achieved and it is indeed a great metallurgical achievement. Further, from the copious information put before him, he can in some measure estimate to what extent there can be hope, not only of better things to come, but also of their probable magnitude.—P. L. TEED.

INTRODUCTION TO THE DESIGN OF SERVOMECHANISMS. *J. L. Bower and P. M. Schultheiss. John Wiley and Sons, New York; Chapman and Hall, London, 1958. 510 pp. Illustrated. 104s.*

Introductory textbooks on servo-mechanisms are now so common that a new one does not fulfil a basic need but merely adds to the general pool. This book is no exception. The material is taken from courses given (presumably by the authors) at Yale University. The text follows the familiar but logical flow pattern; after a few preliminaries, it starts with the necessary mathematics, follows with the application to linear systems of harmonic, root-locus and statistical methods, and ends with a chapter on non-linearities. A brief description of components used in examples is given in an appendix.

The authors teach by the liberal use of examples. This leads to a ready understanding and remembrance of the methods. It also allows mention of many practical techniques which might otherwise be overlooked. Unfortunately, it results in a long text and a high price.

The word "design" is included in the title but, as may be expected, most of the book is concerned with presenting the basic analytic tools for the servo-mechanism designer. However, there are good chapters on the synthesis of series and feedback conmpensating networks using Bode diagram methods. In fact the major contribution of the book to design methods is via the Bode diagram. Although a whole chapter is devoted to the root-locus technique, few suggestions are given to show how it can be used for synthesis as distinct from analysis. The chapter on statistical considerations does little more than derive the relationship between the spectral densities of the input and output of a linear system. The methods of Wiener are given no more than a brief reference. Finally, in the chapter on non-linearities, the authors deal with the design of a system for operation within a limited linear range, small perturbation methods, and the usual phase-plane and describing function ideas.

The book is fairly accurate except that some erroneous contours appear mysteriously on the diagram of a Nichols chart. Most of it is written in a readily digestible form and numerous problems are set at the end of each chapter. It is unfortunate that the price will place it beyond the reach of the majority of students.—A. P. ROBERTS.

GAS DYNAMICS. *A. B. Cambel and B. H. Jennings. McGraw-Hill, London, 1958. 415 pp. Illustrated. 85s. 6d.*

In the preface the authors state "This book has been written to provide the advanced undergraduate and the beginning graduate student with a function of the theory and concepts underlying compressible-fluid flow and combustion."

To the reviewer there are two reasons for writing such a book, either to present new information or to present standard theory in a form which is easier to comprehend. This book appears not to present new information. It collects together in one work standard theory and the contents of technical papers which may not have appeared in a book before.

Where it reproduces existing information, it seems to have copied the standard presentation and has cast little new light on the subjects considered. There are cases where a modern book has little excuse for not adding something to the presentation of old theory. There are better methods of presenting equations dealing with moving waves than the Rankine-Hugoniot equation. There is the tendency, which is not uncommon, to appeal to entropy when dealing with wave phenomena rather than understanding the physical processes which lead to a particular state. A good test of the presentation was a section with which the reviewer was not very familiar. This is thermo-chemistry, where the arguments leading to the derivation of equilibrium constants are presented. The fault may lie with the reviewer but there seemed to be little attempt to give more than an academic presentation which started from Gibbs Thermo-

dynamic Potential and left one with no real feeling for the physics of the process being considered.

The last half of the book deals with flames and combustion. The substance of this section appeared to be sound but very rarely drew attention to those problems which normally have to be solved on a "trial and error" basis in the combustion engineering field. In the section dealing with flame stabilisation, there appeared to be no mention of the fact that reducing pressure has a serious effect on combustion stability. There was some discussion of a method of stabilising a flame by opposing streams, thus removing the need for a stabiliser. This is presented as if it was an original idea—which it is not—and no attempt is made to point out that in practice this system has not worked well so far, due to weak re-circulation.

Detonation waves in combustible mixtures are treated somewhat superficially, which could be forgiven in a work of this nature if it had been indicated that the subject was too wide for a book of this type. There is no attempt to show how to calculate the velocity of detonation waves nor any mention of the peculiar phenomena of spinning detonation.

This book might be a useful adjunct to a course of lectures in a university where direction could be given for other reading. The authors have made a valiant attempt to provide a large number of references, a list being given at the end of every chapter. However, there appears to be no mention of some very old friends—such as Professor Bone's book on combustion.

There is a useful collection of tables at the end of the book—properties of the standard atmosphere; constants for gases and vapour; thermodynamic properties of air at low pressures; frictionless, constant-area flow with change in stagnation temperature which is reproduced from Shapiro, Hawthorne and Edelman's paper "The Mechanics and Thermodynamics of Steady One-Dimensional Gas Flow." There is a table for frictional adiabatic constant-area flow from the same source; a table of enthalpies of some fuels, oxidants and diluents; enthalpies and entropies of various species; a table of empirical specific heat equations for a variety of gases; a table of functions for the method of characteristics and an explanatory diagram.

To students coming entirely fresh to the subject, this book may be helpful because so much is collected in one volume. In any section one will find only the standard treatment of those subjects which are amenable to theory or a superficial view of those which are not.—L. G. DAWSON.

SYNTHESIS OF LINEAR COMMUNICATION NETWORKS. Vols. I and II. *Wilhelm Cauer. McGraw-Hill, New York, 1958. 862 pp. Illustrated. 151s.*

To those familiar with network theory the publication of this book in English is seventeen years overdue. The fact that it has eventually been produced is a tribute to the greatness of the author. Few will quarrel if it is said that Cauer was the founder of modern network synthesis, and that this book is a classic. First published in 1941 in his native German, under the modest title *Theorie der linearen Wechselstromschaltungen*, it represents a summary of some thirteen years of pioneering activity.

The great majority of the subject matter is familiar and even commonplace to communication engineers of today, but the work should be considered in the light of its original publication, when it was undoubtedly the first text book of its kind. An introductory chapter describes the basic concepts of linear network theory and the subsequent application of this theory to the synthesis of networks possessing desired frequency responses. The salient problem of the day was the design of telecommunication filters so that the treatment in this and subsequent chapters is weighted towards this particular type of network. The following chapters discuss in much finer detail the nature of the problem, in the course of which a great many theorems are developed. Cauer makes great use of the powerful matrix algebra and topological methods in his treatment, which clearly demonstrate his profound realisation of the underlying generalisations hitherto largely unrecognised.

Throughout the translation the original German symbols have been used in the analysis. These to English speaking readers look somewhat unfamiliar. The translators may well have had good reasons for this since cross-checking was made easier. However, the German notation can be justified if only to enhance the classic nature of the book. Few engineers would use it as a text book since the subject is nowadays presented in a rather more sophisticated way. Nevertheless, for the serious student of network synthesis it is a well established and essential foundation of his reading at long last available in English.

Many thorny problems still exist in network synthesis, and although Cauer pointed the way, the problem of realisation is still far from being completely understood. Modern theory has now gone far beyond Cauer's original work, and the translators have added an appendix which gives a concise guide and many excellent references to more contemporary developments.

Cauer's contribution was revolutionary and this book, so accurately translated, is a credit to all who undertook this much needed English presentation.—K. C. GARNER.

AIRCRAFT ELECTRICAL ENGINEERING. *Edited by G. G. Wakefield. Chapman and Hall, London, 1959. 347 pp. Illustrated. 50s.*

"Aircraft Electrical Engineering" is a book based on a series of papers given at the Imperial College of Science and Technology in September 1954. This in itself means that the individual chapters are highly specialised and are written by experts in their particular field. On the other hand, reading this book in 1959, nearly five years after the papers were first prepared, it is apparent that some are already out of date.

This does not apply to a number of the chapters, such as that dealing with the cooling of aircraft electrical machines, which can stand by themselves as standard works of reference. Some chapters, and here I would mention those dealing with direct current and alternating current machines, require a fairly extensive knowledge of electrical engineering before studying them, and in this respect they are ideal for electrical engineering graduates entering the aircraft industry.

One serious omission, both for readers who are electrical engineers and for aircraft people as a whole, is a chapter on the utilisation of electrical energy in aircraft, and the factors influencing the choice of an electrical device rather than one which is operated by hydraulics or some other form of auxiliary power. Such a chapter would explain the undoubted trend towards an alternating current primary system in place of the 28 volts direct current system which had a monopoly a few years ago. The aspect of reliability with respect to aircraft electrical systems could also, to advantage, have been enlarged.

The advance in constant speed drives, and perhaps more important, that in the application of semi-conductors, is having a profound effect on the development of electrical equipment and systems, and more space could have been given to these subjects.

In making a review of this kind there is a tendency to concentrate on the omissions, and I would not like to leave the impression that the book falls short in its essential function. As a basic textbook for people entering the profession it is excellent. It also provides much valuable reference work which is useful for those already in the Aircraft Industry. It is, I believe, the first serious attempt to produce a textbook covering this subject and it satisfies, to a great extent, this requirement. The reader is taken briefly through the historical background of the subject and is brought up to the last breed of aircraft in a very comprehensive manner. He is left wondering about present developments and I hope it will not be too long before a second volume covering this is available.—D. C. FLACK.

HEAVENLY ADVENTURER: Sefton Brancker and the Dawn of British Aviation. *Basil Collier. Secker and Warburg, London, 1959. 242 pp. Illustrated. Index. 25s.*

Neither the start nor the finish of Air Vice-Marshal Sir W. Sefton Brancker's double-decade association with aviation were of his own volition. He was an artillery captain on staff duty at Calcutta in 1910 when Farnall Thurstan and Henri Jullerot arrived from the British and Colonial Aeroplane Company (forerunner of Bristol) with a couple of boxkites. As self-appointed observer to pilot Jullerot, Brancker handed in the first official report ever made to a British general from an aeroplane reconnaissance.

Two years later Brancker was posted home and to the War Office. Chance offered him duty in the Military Aeronautics Directorate. From then onwards aviation claimed him as a devotee. His eyesight was bad—his monocle was necessary, not an adornment—but he learned to fly and obtained R.Ae.C. certificate No. 525 on 18th June 1913, ten months after Trenchard, then his wings. Never a good pilot, his landings were atrocious. He never flew in combat. For all but a few brief months his military work was at the War Office and the Air Ministry.

When Sir David Henderson went to France in 1914 Brancker was left as Henderson's deputy to handle all War Office responsibility for Army aviation on the rank of lieutenant-colonel. He worked hard to get men, aircraft, aerodromes, to train pilots, to feed the growing force in France. If he favoured too much the very stable B.E.2c, it was a natural choice for a man who was a poor pilot, for that machine could take off unaided and almost land itself. Moreover, Brancker was inclined to support the official Royal Aircraft Factory because of his training at Woolwich and life in the Army. But, after assessing all his handicaps he did his work well, until, finding his humble rank too inhibiting, he wrote telling Henderson that his duty as Director-General of Military Aeronautics lay in Whitehall not in France.

That began the reshuffle. Henderson came home, Brancker departed to command a wing in France but was soon given a training brigade at home, then made Director of Air Organisation in the War Office.

When he heard that Henderson was to be succeeded by General Capper (whose knowledge of aviation was of the balloon age) Brancker wrote to Lord Derby a letter of strong objection. He was officially rebuked for writing out of turn, but instead of Capper, John Salmond took over and Brancker went to command in Egypt and Palestine.

With his long experience of staff work he was soon recalled to become Controller-General of Equipment in the new Air Ministry. The first Air Council worked on creaking hinges; Rothermere and Trenchard were so widely different in personality and in outlook that no bridge could join them. Trenchard resigned. Henderson resigned. Then Rothermere. On Brancker's return from a mission to America he obtained the post of Master-General of Personnel and so dived headlong into the personality-clash between the Hon. Violet Douglas-Pennant, first commandant of the W.R.A.F., and her subordinates. Contrary to correct usage for her military appointment, apart from the merits of her case, he summarily dismissed her. By this unwisdom Brancker vitiated whatever chance he had had of greatness in the post-war R.A.F. Basil Collier devotes over 60 pages to Miss Douglas-Pennant, many of them not directly concerned with Brancker.

In the aftermath Brancker decided to abandon his military career in favour of civil aviation. He became the directing power of Britain's first commercial air transport venture, the Holt Thomas-financed Air Travel and Transport which operated between London and Paris from August 1919 but closed down in 1920. Brancker was unemployed, with a private income of about £500 a year.

For 18 months he barnstormed in lecture halls and wrote letters to the Press on the iniquity of treating civil aviation as an unwanted child. After Sykes refused to renew his three year term as Controller-General of Civil Aviation the Government's most outspoken critic, Brancker, succeeded to the lesser appointment as Director of Civil Aviation. He now entered the great rôle of his life. With constructive work to perform he was in his element, a good mixer with all classes, debonair, tireless in his work, an almost unsleeping ambassador of goodwill for civil flying in all its branches at home and overseas.

Although not all of his activities are mentioned by Basil Collier (the R.Ae.S. is not anywhere referred to) those who knew Brancker will recognise a valid portrait of the surface man in this well-written biography. Seldom seen is that serious-minded inner man he hid so carefully behind the visible visage of glittering gaiety. It emerges in his fears for the safety of the R.101 and in his forebodings of personal disaster. He searched for a technical formula that might stay the departure of the inadequately tested ship, but he sailed in her against his better judgment.

This is a book about men, manners, politics and the continual struggle for promotion, position and its retention once achieved. Brancker's situation among them is well portrayed, but it does not make him greater to lower his contemporaries; rather would he loom the larger by their greatness; when they shrink, he shrinks. There are still many yet alive who know all these men and some of these may not agree with the author's opinions of the statures of some of the dead men whose literary ghosts pass through his lively pages in the company of the ebullient Sefton Brancker during 20 formative years of British aviation. Retrospectively his world looks a different world from that of today, mechanically a pigmy world, humanistically not so small because men appear to have had more value as individuals then than now. Certainly none has ever replaced Brancker. Perhaps none ever will, for he was a man with a great heart, which controls actions so differently from the governance of the head. He was the heart and soul of the party. Perhaps that is why he was never the head of the Air Force.—NORMAN MACMILLAN.

APPLIED MECHANICS. *J. A. Cormack. Chatto and Windus, London, 1959. 342 pp. Illustrated.* **30s.**

Correction:

In the review of this book, published in the March JOURNAL (p. 187), we regret that the price was incorrectly given as 42s.

Additions to the Library

Aircraft Electrical Engineering. G. G. Wakefield (*Editor*). Chapman and Hall, London. 1959. 347 pp. Illustrated. 50s. *To be reviewed.*

Aircraft Year Book, The (1959). 40th Edition. James J. Haggerty (*Executive Editor*). American Aviation Publications, Washington. 1959. 486 pp. Illustrated. $6. This is a profusely illustrated review of the American scene, divided into chapters with such headings as "The Industry," "Military Aviation," "Civil Aviation" (subdivided into three headings) and so on. Useful reference material such as chronologies, records, and a bibliography are also given. The editors have contrived to cover "Missiles" with only two more pages than in the last edition. The 108 page section of "Aircraft in Production" comes under the heading, here, of "Food for Thought."

Civil Air Regulations and Flight Standards for Pilots. Associated Aeronautical Staff of Aero Publishers Inc. Aero Publishers, Inc., Los Angeles. 1959. 120 pp. Illustrated. $2.50. This 21st edition is only a year older than the 20th and it is evident, therefore, that Aero Publishers do a real service for American pilots by keeping them up-to-date with the many regulations they must know.

Combustion and Propulsion, Third Agard Colloquium. Edited by J. Fabri, A. H. Lefebvre, O. Lutz and M. W. Thring. Pergamon Press. 1958. 614 pp. Illustrated. 140s. *To be reviewed.*

Dynamics of Flight. B. Etkin. Chapman and Hall, London. 1959. 519 pp. Illustrated. 120s. *To be reviewed.*

Fundamentals of Transistors. L. Krugman. Chapman and Hall, London. 1958. 167 pp. 25s. A second edition of a book first published in 1954 and reviewed in the March 1955 JOURNAL (p. 228). It gives initial knowledge of the principles and practice of transistors and useful information on practical circuit applications. The revision has brought the book up to date and problems and references for further study are now included at the end of each chapter.

Guided Missile Engineering. Edited by Allen E. Puckett and Simon Ramo. McGraw-Hill, London. 1959. 496 pp. Illustrated. 77s. 6d. *To be reviewed.*

High Speed Computing. S. H. Hollingdale. English Universities Press. 1959. 244 pp. Illustrated. 25s. *To be reviewed.*

Intra-European Air Cargo Traffic 1953-1957. A.R.B./187. Air Research Bureau, Brussels. 1958. 33 pp. Tables, maps attached.

Introduction to Monopulse. Donald R. Rhodes. McGraw-Hill, London. 1959. 119 pp. Illustrated. 46s. 6d. *To be reviewed.*

Knight of the Air. Maxwell A. Smith. Cassell, London. 1959. 228 pp. 18s. *To be reviewed.*

Modern Transistor Circuits. John M. Carroll. McGraw-Hill, London. 1959. 268 pp. Illustrated. 66s. *To be reviewed.*

Recommendations of the International Commission on Radiological Protection. Published for the International Commission on Radiological Protection by Pergamon Press, London. 1959. 18 pp. 3s. 6d. This commission has been functioning since 1928 but with the development of atomic power its work has assumed supreme importance. The recommendations deal with such subjects as occupational exposure, exposure of individuals, of special groups and of the population. Radiation hazards appear to have taken over from where gas protection was in about 1938, the difference being that now the risk is always with us.

Royal Air Force, The. John W. R. Taylor. Ian Allan, London. 1959. 40 pp. Illustrated. 2s. 6d. A new edition of the booklet published in 1957 and reviewed in the October 1957 JOURNAL (p. 704). The same size, but brought up to date to include the latest aircraft and missiles.

Sounding Rockets. H. E. Newell. McGraw-Hill, London. 1959. 334 pp. Illustrated. 97s. *To be reviewed.*

Traffic and Operating Data, A.R.B. Carriers, 1954-1957. A.R.B./198. Air Research Bureau, Brussels. 1958. 9 pp. Tables, statistics and graphs attached.

War and Peace in the Space Age. Lt. Gen. James Gavin. Hutchinson, London. 1959. 287 pp. 21s. *To be reviewed.*

Papers presented at the S.A.E. National Aeronautic Meeting, New York (31st March-3rd April 1959).

Number

43R The machining of ultra strength alloys. J. Maranchik *et al.*

43S Progress in space age materials fabrication. L. E. Laux and C. S. Hill.

44R The shopman's operations research. H. D. Hall.

44S The cost improvement story at Arma. F. J. Morgan.

45R Requirements guidance and control systems impose on manufacturing departments. C. McWilliams.

45S Manufacturing problems—electronic guidance and control. H. E. Rice.

46S The production of reliable electronics in the space age: consistency—the production man's key to reliability. J. M. Wuerth.

47R The effects of kerosene type fuels on the design and operation of a jet transport. F. K. Brunton and J. C. Deweese.

47S Orenda engine experience with service fuels. A. L. Sutton.

47T Can we define aircraft turbine fuel cleanliness requirements? G. T. Coker *et al.*

48R Handling the commercial jet airplane on the ground. J. F. Horan.

48S Continuous air source packs for jet engine starting and air conditions. F. P. Carr and S. Kalikoff.

49R Design approach to the Allison model 250 engine. R. S. Hall.

49S Anti-icing for the gas turbine helicopter engine—the development of a system for the T53. T. A. Dickey *et al.*

49T N.A.S.A. research bearing on jet engine reliability. S. S. Manson *et al.*

50R Designing for use of Viton "O" rings at elevated temperatures. F. H. Pollard.

50S Seals, the vulnerable giants. C. E. Hamlin.

50T High temperature sealing studies of missile hydraulic components. A. B. Billet.

50U Fluid sealing in extreme environments. A. A. LePera.

50V Properties of silicone rubber for high temperature static seals. H. E. Todd and J. F. Miazga.

51R How to apply human engineering principles to maintainability design of weapon systems. G. F. Rabideau.

51S Relaxed alertness in the cockpit. J. Lederer.

51T Human factor aspects of decompression in high altitude transport operations. C. P. Seitz and F. Elliott.

52S Prediction in new metal joining processes. J. J. Chyle.

52T Looking ahead the next 10 years in manufacturing by the high energy rate plastic deformation of materials. J. B. Ottestad.

53R Positive-displacement motors for A.P.U. power requirements. F. Klemach.

53S The modern gas turbine auxiliary powerplant—characteristics and applications. P. G. Stein.

53T Non-air-breathing auxiliary powerplants. D. L. Cochran *et al.*

54R The design and operation of propulsion systems for cruise-type missiles. S. Shrage.

54S Factors influencing the application of unconventional rocket engine systems. G. S. Gill and L. Kusak.

54T Considerations in the application of evaporative cooling systems to hypersonic vehicles. E. Kaplan.

55R Pyrophorics for aircraft propulsion: their promise and problems. M. C. Hardin and F. J. Verkamp.

55S High performance hydrocarbon fuels for supersonic propulsion. M. E. Conn and W. G. Dukek.

55T The place of solid propellants in space vehicle propulsion. B. F. Wilkes.

56R Research on high-strength, extreme-temperature structures. A. R. Lytle.
56S Refractory nonmetals for use in hypersonic aircraft. J. M. Nowak.
56T The development of refractory sheet metal structures. A. V. Levy and S. E. Bramer.
57R Investigations of acoustic, thrust, and drag characteristics of several jet noise suppressors. E. E. Callaghan.
57S Design, development and operational experience of the Boeing 707 thrust reverser/sound suppressors. J. E. Barfoot.
57T Rectangular nozzles for jet noise suppression. J. M. Tyler *et al.*
58R The collision prevention problem. F. C. White.
58S Optical techniques for collision warning. L. H. Chasson.
58T An approach to organisation of the air space. J. E. Basanese.
59R Current trends in storable propellants. J. Silverman and S. A. Greene.
59S Some development problems with large cryogenic propellant systems. D. A. Heald.
59T Thrust magnitude control of solid-propellant rocket motors by mechanical means. J. S. Gates and S. L. Pinto.
60R Landing and take-off performance. A definition of the problem—especially required by SR-422A. M. B. Spaulding.
60S Jet transport problems during take-off and landing. W. R. Rhoades and R. E. Coykendall.
60T Ways of improving take-off and landing. F. W. Kolk.
61R Comparative cost and effectiveness of manned aircraft and guided missiles in air defense. H. K. Weiss.
61S The role of manned systems in aero/astronautics. R. D. Roche.
62R The introduction of jet transport. C. H. Jackson.
62S The Lockheed Electra—what it is, and what it does. C. Froesch.
63R Nuclear rockets for interplanetary propulsion. F. E. Rom and P. G. Johnson.
63S Electric propulsion systems. V. P. Kavacik and D. P. Ross.
63T Electric propulsion—measurements with a small thrust plasma generator. B. Gorowitz and B. W. Harned.
64R Jet powerplant requirements for VTOL. C. T. Hewson.
64S A propulsion spectrum for VTOL aircraft. D. A. Richardson.
64T The effect of vertical flight on powerplant design. J. A. O'Malley and A. M. Jackes.

Reports

AERODYNAMICS

BOUNDARY LAYER—*see also* CONTROLS
THERMO-AERODYNAMICS
TESTING AND INSTRUMENTS

Experiments with a two-dimensional aerofoil designed to be free from turbulent boundary layer separation at small angles of incidence for all Mach numbers. D. W. Holder and R. F. Cash. R. & M. 3100. 1959.—(1.1.4 × 1.10.2.1).

Boundary layer transition on hollow cylinders in supersonic free flight as affected by Mach number and a screwthread type of surface roughness. C. S. James. N.A.S.A. Memo 1-20-59A. *TIL* 6208. *Feb.* 1959.—(1.1.2.4).

Experimental investigation of the pressure rise required for the incipient separation of turbulent boundary layers in two-dimensional supersonic flow. D. M. Kuehn. N.A.S.A. Memo 1-21-59A. *TIL* 6209. *Feb.* 1959.—(1.1.4.4).

Some finite difference solutions of the laminar compressible boundary layer showing the effects of upstream transpiration cooling. J. T. Howe. N.A.S.A. Memo 2-26-59A. *TIL* 6210. *Feb.* 1959.—(1.1.1.4 × 1.9.1).

An equation for the mean velocity distribution of boundary layers. V. A. Sandborn. N.A.S.A. Memo 2-5-59E. *TIL* 6214. *Feb.* 1959.—(1.1).

An experimental study at a Mach number of 3 *of the effect of turbulence level and sandpaper-type roughness on transition on a flat plate. R. A. Jones. N.A.S.A. Memo* 2-9-59L. *TIL* 6271. *March* 1959.—(1.1.2.4).

The interaction of an oblique shock wave with a laminar boundary layer. R. J. Hakkinen et al. *N.A.S.A. Memo* 2-18-59W. *TIL* 6276. *March* 1959.—(1.1.1.4 × 1.2.3.2).

Use of a Stanton tube for skin friction measurements. S. S. Abarbanel et al. *N.A.S.A. Memo* 2-17-59W. *TIL* 6275. *March* 1959.—(1.1.2).

Investigation of separated flows in supersonic and subsonic streams with emphasis on the effect of transition. D. R. Chapman et al. *N.A.C.A. Report* 1356. 1958.—(1.1.2.2 × 1.1.2.4).

Simplified analysis of boundary layer oscillations. R. Betchov. Douglas Report ES 29174. *March* 1959.—(1.1.0.1).

Investigations of free-molecule and transition flows near the leading edge of a flat plate. E. L. Harris. U.T.I.A. Report 53. *Nov.* 1958.—(1.1 × 1.12.5).

Corner interference effects. K. Gersten. DFL-Bericht 108. *Feb.* 1959.—(1.1.0.1).

*Nachprüfung der einfachen Rechenmethode fur dreidimensionale laminare Grenzschichten mit Hilfe von exakten Losungen. J. A. Zaat. NLL Bericht TR F.*202. *June* 1957. (In German.)—(1.1).

COMPRESSIBLE FLOW—*see also* BOUNDARY LAYER
CONTROLS

The flow of chemically reacting gas mixtures. J. F. Clarke. CoA Report 117. *Nov.* 1958.—(1.2.3.1).

Subsonic drag and pitching moment characteristics of slender cambered bodies. K. D. Harris. CoA Report 118. *Sept.* 1958.—(1.2.1).

Investigation of spherical-wave-initiated flow fields around bodies. D. R. McFarland. N.A.S.A. Memo 1-6-59L. *TIL* 6199. *Feb.* 1959.
A bullet-optical technique was used to obtain measurements of the velocity flow fields and vortex movements about various blunt-shaped bodies undergoing a spherical blast wave with a peak positive over-pressure of 4 lb./in.^{2}.—(1.2.3.2 × 1.6.3 × 1.2).

Experimental investigation of coaxial jet mixing of two subsonic streams at various temperature, Mach number and diameter ratios for three configurations. R. R. Burley and L. Bryant. N.A.S.A. Memo 12-21-58E. *TIL* 6229. *Feb.* 1959.—(1.2.1).

Pressure distributions at transonic speeds for bumpy and indented midsections of a basic parabolic-arc body. R. A. Taylor. N.A.S.A. Memo 1-22-59A. *TIL* 6197. *Feb.* 1959.—(1.2.2).

An experimental investigation of sting-support effects on drag and a comparison with jet effects at transonic speeds. M. S. Cahn. N.A.C.A. Report 1353. 1958.—(1.2.2).

The interaction of a plane shock wave with an inclined perforated plate. W. H. Friend. U.T.I.A. T.N. 25. *Oct.* 1958.—(1.2.3.2).

CONTROLS—*see also* WINGS AND AEROFOILS

Interaction effects produced by jet exhausting laterally near base of ogive-cylinder model in supersonic main stream. P. W. Vinson et al. *N.A.S.A. Memo* 12-5-58W. *TIL* 6195. *Feb.* 1959.—(1.3.6 × 1.2.3 × 1.5.1).

Semi-empirical procedure for estimating lift and drag characteristics of propeller-wing-flap configurations for vertical- and short-take-off-and-landing airplanes. R. E. Kuhn. N.A.S.A. Memo 1-16-59L. *TIL* 6220. *Feb.* 1959.—(1.3.4).

Full scale wind tunnel investigation of a jet flap in conjunction with a plain flap with blowing boundary layer control on a 35° *sweptback-wing airplane. K. Aoyagi and D. H. Hickey. N.A.S.A. Memo* 2-20-59A. *TIL* 6261. *March* 1959.—(1.3.4 × 1.1.6.1).

INTERNAL FLOW—*see also* CONTROLS
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A note on the control of secondary flow by using cascades of twisted blades. Moira E. Martin. C.P. No. 425. 1959.—(1.5.4).

An experiment to determine the position of an equivalent actuator disc replacing a blade row of a turbo-machine. J. H. Horlock and E. C. Deverson. C.P. No. 426. 1959.—(1.5.3.1).

Estimated performance of radial-flow exit nozzles for air in chemical equilibrium. G. W. Englert and F. D. Kochendorfer. N.A.S.A. Memo 1-5-59E. *TIL* 6212. *Feb.* 1959.—(1.5.1×27).

Effect of stator and rotor aspect ratio on transonic-turbine performance. R. Y. Wong and D. E. Monroe. N.A.S.A. Memo 2-11-59E. *TIL* 6215. *Feb.* 1959.—(1.5.3.1).

A hydrogen peroxide hot-jet simulator for wind tunnel tests of turbojet-exit models. J. F. Runckel and J. M. Swihart. N.A.S.A. Memo 1-10-59L. *TIL* 6267. *Feb.* 1959.—(1.5.1×1.12).

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WINGS AND AEROFOILS
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Analysis of acceleration, airspeed and gust-velocity data from a four-engine transport airplane operating over a north-western United States-Alaska route. J. N. Engel and M. R. Copp. N.A.S.A. Memo 1-17-59L. *TIL* 6268. *Feb.* 1959.—(1.6.3).

A theory of the response of airplanes to random atmospheric turbulence. B. Etkin. U.T.I.A. Report 54. *May* 1958.—(1.6.3×24).

Efforts aérodynamiques non stationnaires sur une aile mince de très faible allongement en déformation. J. P. Giraud. O.N.E.R.A. Pub. 95. 1959. (In French.)—(1.6.3×2×1.10.1.2).

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FLIGHT TESTING

Use of flight simulators for pilot-control problems. G. A. Rathert et al. *N.A.S.A. Memo* 3-6-59A. *TIL* 6211. *Feb.* 1959.—(1.8.0.1).

A pilot opinion study of lateral control requirements for fighter-type aircraft. B. Y. Creer et al. *N.A.S.A. Memo* 1-29-59A. *TIL* 6259. *March* 1959.—(1.8.1.1).

Pitch-up problem—A criterion and method of evaluation. M. Sadoff. N.A.S.A. Memo 3-7-59A. *TIL* 6260. *Feb.* 1959.—(1.8.1.1).

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STRUCTURES—THEORY AND ANALYSIS
THERMODYNAMICS

Two-dimensional, supersonic, linearized flow with heat addition. H. Lomax. N.A.S.A. Memo 1-10-59A. *TIL* 6196. *Feb.* 1959.—(1.9×27).

Details of exact low Prandtl number boundary layer solutions for forced and for free convection. E. M. Sparrow and J. L. Gregg. N.A.S.A. Memo 2-27-59E. *TIL* 6264. *Feb.* 1959.—(1.9.1×34.3.2×1.1.1.1×27.6).

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LOADS
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An improvement of the velocity distribution predicted by linear theory for wings with straight subsonic leading edges. D. G. Randall. C.P. No. 418. 1959.—(1.10.1.2).

Subsonic wing loadings on a 45° sweptback-wing body combination at high angles of attack. J. A. Axelson and J. F. Haacker. N.A.S.A. Memo 1-18-59A. *TIL* 6206. *Feb.* 1959.—(1.10.2.2×1.6.1).

Low-speed wind tunnel investigation to determine the aerodynamic characteristics of a rectangular wing equipped with a full-span and an inboard half-span jet-augmented flap deflected 55°. *T. G. Gainer. N.A.S.A. Memo* 1-27-59L. *TIL* 6224. *Feb.* 1959.—(1.10.2.2×1.8.2.2×1.3.4).

Non-linear airfoil theory for rectangular wings in compressible flow. K. Gersten. N.A.S.A. RE 3-2-59W. *TIL RPN* 4. *Feb.* 1959.—(1.10.1.2).

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Linearized theory of lifting sweptback wings at sonic speed. W. Eckhaus and E. M. De Jager. NLL Report TR F206. *Sept.* 1957.—(1.10.1.2).

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Parasite-drag measurements of five helicopter rotor hubs. G. B. Churchill and R. D. Harrington. N.A.S.A. Memo 1-31-59L. *TIL* 6226. *Feb.* 1959.—(1.11.3).

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Model tests on an effuser induction scheme for operating a transonic wind tunnel. D. A. Spence and A. S. Bennett. C.P. No. 420. 1959.—(1.12.1.2×1.5.1.4).

Flight tests of a simple method of measuring pressure distributions on a wing. W. G. A. Port and J. C. Morrall. C.P. No. 422. 1959.—(1.12.5).

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DESIGN AND CONSTRUCTION

See AERODYNAMICS—TESTING AND INSTRUMENTS
STRUCTURES—LOADS

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A comparison of two types of visual approach aid. R. H. Day and J. R. Baxter. ARL Note HE 4. *Jan.* 1959.—(5.3×9).

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Lubricating properties of lead-monoxide-base coatings of various compositions at temperatures to 1250°*F. H. E. Sliney. N.A.S.A. Memo* 3-2-59E. *TIL* 6216. *Feb.* 1959.—(14).

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STRUCTURES—THEORY AND ANALYSIS

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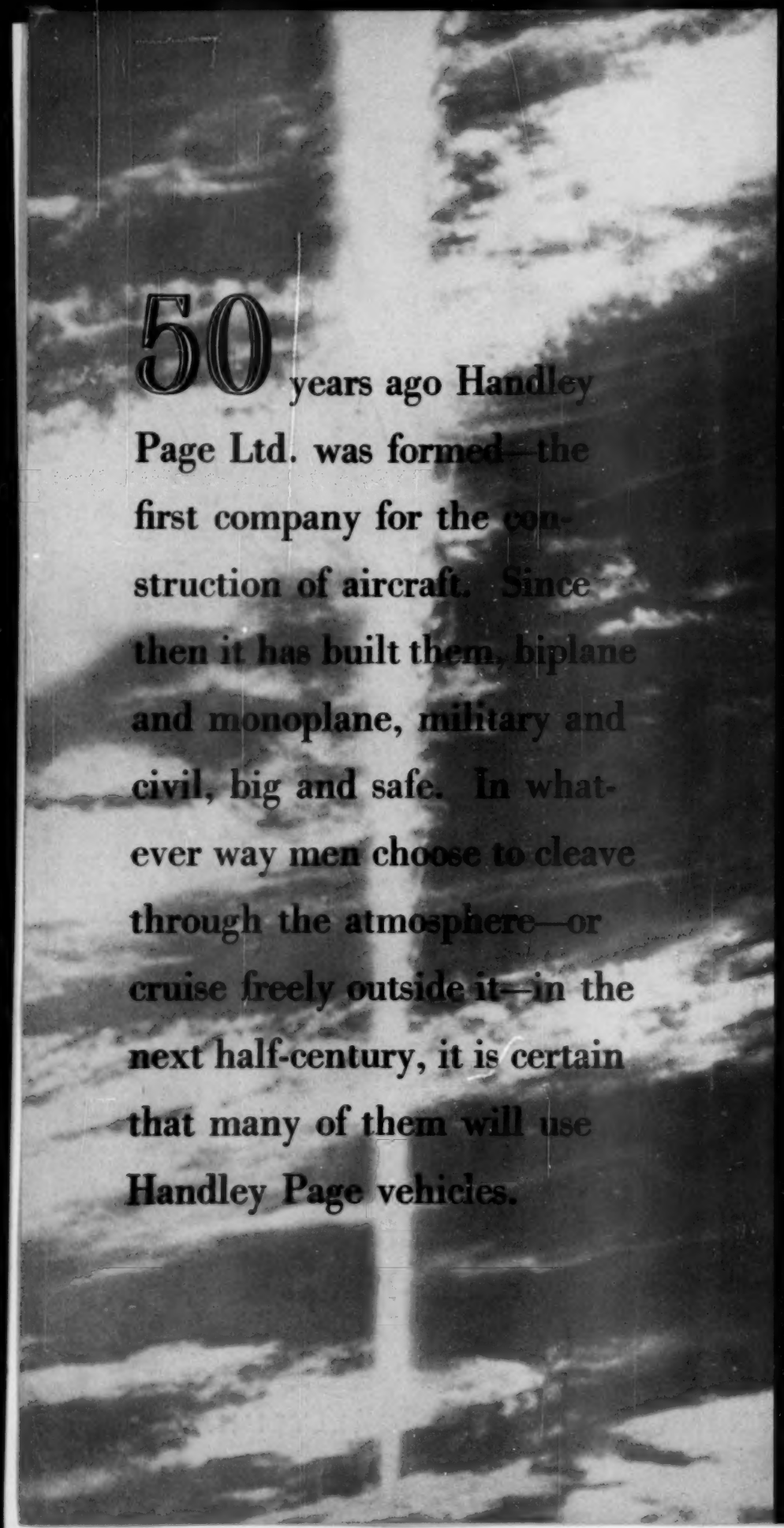

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